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Combustion of Anthracite-Bituminous Coal Blends in a Spreader Stoker Boiler at Holston Army Ammunition Plant

by
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The Department of Army was required by Section 8110 of the Fiscal Year 1986 Defense Appropriations Act (PL99-190) to consume more anthracite coal in the United States. To this end, a test program was conducted at the Holston Army Ammunition Plant near Kingsport, TN to evaluate the combustion of an anthracite-bituminous coal blend in a spreader stoker boiler designed for bituminous coal only. The test program was structured to evaluate different percentages of anthracite and bituminous in the blend at different operating loads on the boiler. Blends of 15, 22, 30 and 42 percent anthracite were combusted at loads of 62.5, 60, and 37.5 percent of the maximum continuous rating (MCR) boiler capacity. Stack testing and ash sampling were performed to monitor combustion performance, in addition to visually inspecting the ash bed. The testing disclosed no technical reasons why anthracite-bituminous blending could not be performed on a long term basis to meet targeted Army anthracite consumption tonnages.

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FOREWORD

This study was conducted for the Facilities Engineering Division (now part of the U.S. Army Engineering and Housing Support Center [USAEHSC]), Office of the Assistant Chief of Engineers (OACE), under Funding Authorization Document (FAD) 87-080426, "Anthracite Coal Utilization at Holston Army Ammunition Plant," dated July 1987. The Technical Monitor was Mr. James Donnelly, CEHSC-FU-P.

This research was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. Gilbert R. Williamson is Chief of USA-CERL-ES. USA-CERL contracted with Schmidt Associates, Inc. (SAI) through the Institute of Gas Technology (IGT) to provide coal combustion expertise in developing and conducting the test program to demonstrate the combustion of an anthracite-bituminous coal blend. Mr. Don K. Hartsock is affiliated with SAI.

COL Carl O. Magnell is Commander and Director of USA CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Section 8110 of the Fiscal Year (FY) 1986 Defense Appropriations Act directed the Department of Defense (DOD) to immediately implement a coal conversion program of existing steam generating facilities in the United States. The purpose of the program was to achieve, by FY 1994, a coal consumption target of 1,600,000 short tons* per year above the current DOD consumption levels. This section also directed that DOD purchase 302,000 short tons of anthracite coal in FY 1986.

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) has been asked to provide technical support to both the Army's and DOD's combustion experts to brainstorm and discuss methods for increasing anthracite coal use. Discussion alternatives included: direct conversion of bituminous facilities to anthracite; bituminous and anthracite coal blends; anthracite gasifiers; anthracite coal-oil/water slurries; retrofit slagging combustors; fluidized bed combustion; and new anthracite coal burning facilities. Based on the panel recommendations, the U.S. Army Corps of Engineers technical monitor for this project (CEHSC-FU-P) selected the bituminous-anthracite blending technology for immediate testing.

The panel's recommended overall compliance strategy was formulated to consume the anthracite coal purchase requirement while supporting the DOD goal of consuming more coal in the United States. The strategy goals are to: consume the anthracite coal near the mining region; minimize coal rehandling and storage; and avoid extensive facility modifications. The strategy consists of three separate phases. The first is to prove the technical feasibility of blending bituminous and anthracite coal for use in existing Army coal burning facilities. While this phase does not contribute to the consumption of more coal (anthracite directly replacing an equivalent amount of bituminous), it does fulfill the short-term need to consume more anthracite coal. The second phase (approximately 3 years) is to apply retrofit technologies such as slagging combustors, coal-oil and/or coal-water slurries, and gasifiers for existing gas/oil fired plants. The third and final phase (5 or more years) is new construction of fluidized bed combustion and cogeneration facilities.

In phase one, USA-CERL has done a theoretical evaluation of boilers and coal volatilities to determine which boiler designs could accommodate blended coal. A survey was then made of the Army bituminous coal fired plants within a 500 mile radius of the anthracite coal fields. Holston Army Ammunition Plant (AAP), TN, and the Radford AAP, VA, were selected as prime candidates on the basis of their annual coal consumption tonnage (130,000 to 180,000 ton/yr). Holston AAP uses spreader stoker technology, while Radford AAP uses pulverized coal. The theoretical evaluation had shown that pulverized coal designs were not suitable for blended fuel. Holston AAP was selected as the demonstration site.

*Metric conversion factors are provided at the end of this report (p 42).

Objective

The threefold objective of this demonstration was to:

1. Arrive at a method to blend the two coals into a homogeneous mixture which would have no tendency to segregate within the coal handling system.

2. Successfully combust a bituminous-anthracite coal blend in a traveling grate spreader stoker boiler designed for bituminous coal only.

3. Determine the maximum percentage of anthracite that could be consumed in the blend while achieving both acceptable combustion and boiler operation and compliance with State and Federal environmental regulations.

Approach

An extensive formal testing program was conducted at the Holston AAP for 2 weeks, between July 15 and July 31, 1987. Normal operations using a blend continued for a third week. USA-CERL conducted the test with the cooperation of the Holston Defense Corporation (Operating Contractor), Holston AAP, and Schmidt Associates, Inc. (SAI).

2 GENERAL INFORMATION

Coal Rank

Table 1 depicts the classification of coals by rank (American Society for Testing and Materials [ASTM] Standard D 388, "Standard Classification of Coals by Rank"). This classification of coals by ASTM is the most universally applicable basis for classifying coal according to fixed carbon and heating value calculated on a mineral-matter-free basis. As seen in this table, the transformation of vegetable matter through wood and peat to lignite and finally to anthracite results in a reduction of volatile matter and oxygen content, with a simultaneous increase in carbon content.

The vast majority of coal fields in the United States are bituminous or subbituminous. Anthracite is found in only a few regions. For 1985, of the 883,638,000 short tons of coal mined in the United States, only 0.5 percent (4,708,000 short tons) was anthracite. Because of the availability of bituminous coal, most coal burning equipment in the United States has been designed for it. To burn anthracite, design changes are necessary to account for the lower volatile matter content and the slower burning, higher carbon content. These properties require large furnace volumes and a longer grate retention time to achieve the same combustion efficiency as with bituminous coal.

Combustion

Typically, 25 to 40 percent of the coal is burned in suspension above the grate in a spreader stoker. To do this, the coal must burn rapidly (in less than 0.5 sec). Rapid combustion depends on several factors: moisture, volatile matter, particle size, and temperature. For combustion to occur, the fuel must reach the combustion temperatures of its various components and oxygen must be present. In the first stage of the combustion process, the moisture in the coal evaporates upon exposure to heat. Next, as the particle temperature continues to rise, volatile matter evolves as gas and burns. This produces heat which is absorbed by both the flue gas and the coal particle. The fixed carbon now reaches ignition temperature and burns, radiating heat to the furnace tubes and further heating the flue gas. This whole process is very dependent on the surface area to volume ratio of the coal particle. Trapped moisture must travel from the inside out for the particle temperature to rise, and the fixed carbon particle burns primarily at the surface where oxygen is present. The agglomerating character of the coal (Table 1) indicates whether the coal has a tendency to fuse together and form clinkers on the grate. The key to the rate of combustion is the rate at which heat evolves from burning volatile matter: this evolution of heat starts the fixed carbon burning, while also supplying heat to the boiler for rapid load changes.

Table 1

Classification of Coals by Rank

Class and Group	Fixed Carbon Limits, % (Dry, Mineral-Matter-Free Basis) Equal or Greater Than	Less Than	Volatile Matter Limits% (Dry, Mineral-Matter-Free Basis) Equal or Greater Than	Less Than	Calorific Value Limits, Btu/lb (Moist,[2] Mineral-Matter-Free Basis) Equal or Greater Than	Less Than	Agglomerating Character
Anthracitic							
1. Meta-Anthracite	98	...	...	2	...	...	Nonagglomerating
2. Anthracite	92	98	2	8	...	...	
3. Semianthracite[3]	86	92	8	14	...	...	
Bituminous							
1. Low Volatile Bituminous Coal	78	86	14	22	...	...	
2. Med. Volatile Bituminous Coal	69	78	22	31	...	...	
3. High Volatile A Bituminous Coal	...	69	31	...	14,000[4]	...	Commonly Agglomerating[5]
4. High Volatile B Bituminous Coal	...	...	...	...	13,000[4]	14,000	
5. High Volatile C Bituminous Coal	...	...	...	...	11,500	13,000	
					10,500	11,500	Agglomerating
Subbituminous							
1. Subbituminous A Coal	...	...	...	...	10,500	11,500	
2. Subbituminous B Coal	...	...	...	...	9,500	10,500	Nonagglomerating
3. Subbituminous C Coal	...	...	...	...	8,300	9,500	Nonagglomerating
Lignitic							
1. Lignite A	...	...	...	...	6,300	8,300	
2. Lignite B	...	...	...	...	...	6,300	

NOTES:

1 This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu per pound.

2 Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

3 If agglomerating, classify in low-volatile group of the bituminous class.

4 Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified by fixed carbon, regardless of calorific value.

5 It is recognized that there may be nonagglomerating varities in these groups of the bituminous class, and there are notable exceptions in high-volatile C bituminous group.

Source: American Society for Testing and Materials (ASTM) Standard D 388, "Classification of Coals by Rank."

3 TESTING PROCEDURE

Equipment

Holston AAP Area B Boilerhouse uses continuous-cleaning, traveling-grate spreader stokers to burn bituminous coal. Spreader stokers are used widely in industry today in units requiring steam generation from 10,000 to 400,000 pounds per hour (pph) of steam. One of the reasons the spreader stoker is used is its ability to change steam load rapidly compared with other stoker-type boilers.

All testing was conducted on Boiler No. 1 in the Area B Boilerhouse. Boiler No. 1 is a Babcock and Wilcox "Split 2-Drum No. 42 Single" design, with a maximum continuous rating (MCR) of 160,000 pph of steam at 350 psig, 525 °F superheat. The boiler was built in 1942 and is equipped with a Detroit Stoker rotograte spreader stoker with six feeders and two grates. The flue gas from the boiler flows through an economizer into a Zurn high-efficiency mechanical dust collector. From the multiclone dust collector, the flue gas is pulled into the induced draft (ID) fan and then passes through a three-field Belco electrostatic precipitator (ESP) prior to the stack. To document the condition of all equipment prior to any testing, a thorough visual inspection was made. Figure 1 is a sketch of the boiler and flue gas system indicating the points where samples were taken.

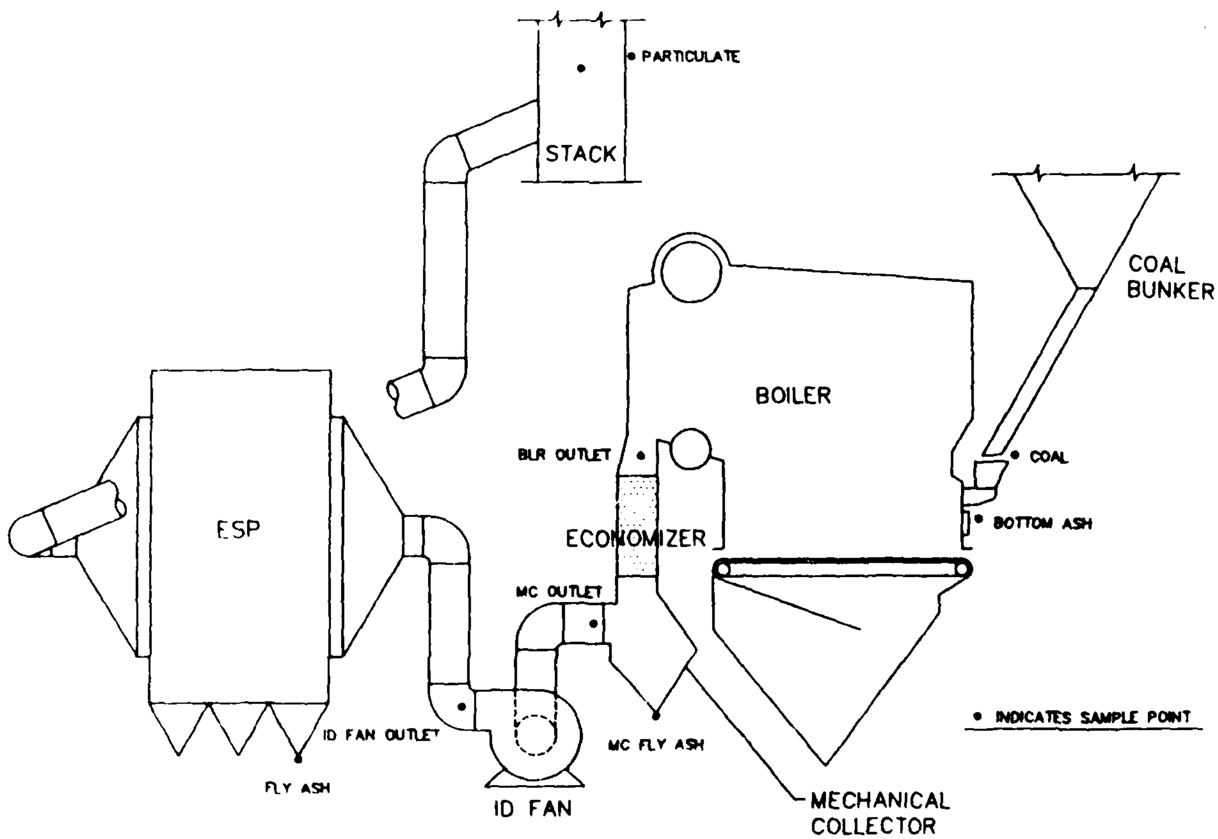

Figure 1. Drawing of Boiler No. 1 with sample points.

Coal Selection

Typically, these are the industry specifications for spreader-stoker-quality coal:

Moisture	0 - 10%
Volatile Matter (VM)	30 - 40%
Fixed Carbon	40 - 50%
Ash	5 - 15%
HHV	12,500 Btu/lb (minimum)

In comparison, Pennsylvania anthracite coal has these characteristics:

Moisture	2 - 7%
VM	0 - 10%
Fixed Carbon	86 - 98%
Ash	4 - 15%
HHV (as fired)	12,500 - 13,500 Btu/lb

It is apparent that anthracite coal alone is not suited for burning in a spreader stoker. For the test at Holston AAP, bituminous coal was selected with a minimum VM of 32 percent and a range of 8 to 10 percent VM was set for the anthracite. In addition to the VM of the two test coals, particular attention was given to the sizing of the coals. Normal spreader coal is 1-1/4 in. by 1/4 in. with 30 percent minus 1/4 in. For the anthracite to combust as quickly as possible on the grate, maximizing surface area for heat transfer and the combustion process is critical. Therefore, anthracite with a size range of 5/16 to 9/16 in. diameter was selected. This size of coal particle maximized surface area while still being large enough to avoid being entrained in the flue gas stream or creating a fuel bed on the grate with insufficient void spacing for combustion air to penetrate.

The bituminous coal Holston AAP receives is run-of-mine (ROM). By definition, ROM coal consists of the product as it comes from the mine without screening. Holston AAP orders 2 in. by 0 in. coal. This is ROM with oversized lumps broken up. However, by observation, the coal contains pieces up to 8 in. in size. Thus, what is received is actually 8 in. by 0 in. The coal is reduced in size by a Knittel ring roll crusher which increases the amount of fines (particles minus 1/4 in. in size). Poor combustion, resulting in fly ash with a high carbon content, could be a result either of incomplete anthracite combustion or of excessive fines in the bituminous coal. This would make it difficult to accurately evaluate the combustion performance of anthracite. To control this amount of fines, double-screened (D.S.) bituminous was purchased specifically for the test program. However, since Holston AAP normally burns ROM bituminous and may not be able to justify the cost differential for D.S. bituminous in the future, it was decided to evaluate anthracite combustion performance using both types of bituminous coal sizing.

Test Protocol

To evaluate combustion of anthracite coal in Boiler No. 1, the test program was structured to vary the percentage of anthracite in the bituminous blend at different boiler steam loads. Ideally, the steam loads would have been set at 100, 80, and 60 percent of MCR or 160,000 pph, 128,000 pph, and 96,000 pph, respectively. However, Boiler No. 1 has been derated to approximately 125,000 pph to meet environmental restrictions. The test loads for each blend were therefore to be 120,000 pph, 100,000 pph, and 80,000 pph; one test using a blend of 30 percent anthracite and 70 percent bituminous

was also scheduled to be done at 60,000 pph to evaluate the turndown capability using anthracite.

The percentage of anthracite in the blends was scheduled to be 10, 20, or 30 percent. Higher anthracite blends were planned for the lower steam rates because of the longer grate retention time. A longer retention time would enable the anthracite coal to burn more completely. The actual test procedure varied slightly from the protocol test plan, as explained later in the report. Baseline data was to be taken for 100 percent D.S. bituminous at 120,000 and 100,000 pph and for 100 percent ROM bituminous at 120,000 pph. Data collected in this way would facilitate comparison between the pure bituminous and the blended coals.

The program shown in Table 2 tests these three factors: steam load, percentage anthracite, and bituminous sizing. Field data taken during individual tests consisted of Environmental Protection Agency (EPA) Method 5 particulate sampling,[1] along with oxygen, temperature, and static pressure measurements taken at the outlets of the boiler, mechanical collector, and ID fan. In addition to actual field measurements, ash samples were collected to perform a carbon balance for each set of test conditions. Boiler control board readings were also recorded. The sample points for the actual field measurements and ash were shown in Figure 1. In addition to the 2-week structured test program shown in Table 2, enough coal was purchased to enable Holston Army Ammunition Plant to burn an anthracite blend for a third week under normal plant operating conditions.

Actual Test Conditions

The actual test conditions obtained during the 3-week testing period are shown in Table 3. A steam load above 100,000 pph could not be consumed by areas serviced, even with every mechanism for applying artificial load used, so all test loads were adjusted accordingly. With the coal blending equipment used, a minimum blend percentage of 15 percent anthracite (by volume) with the D.S. bituminous was obtained, compared to a minimum of 22 percent anthracite with the ROM bituminous. In both cases, this minimum was due to the lowest gate's limit being reached on the anthracite conveyor. Based upon the encouraging results observed during the first week of testing and the first 2 days of the second week, a high blend percentage of 42 percent anthracite was burned at the 100,000 pph steam load.

Procedure

The following discussion describes a typical test day. Preparation for a given test started with the blending of the anthracite and bituminous coal a day before the test. To ensure an accurate determination and evaluation of the combustion characteristics and the effects on the boiler (both short- and long-term), a homogeneous blend is required to eliminate any secondary consequences resulting from a poor blend. The Holston AAP coal handling system consisted of receiving railcars and dumping them either directly at the boilerhouse or at a remote stockpile where the coal was reclaimed by a clamshell and

[1]As specified in Title 40, Code of Federal Regulations (CFR), 1987 revision, Part 60, Appendix A, "Reference Methods."

Table 2

Holston Army Ammunition Plant Test Plan

WEEK 1

MONDAY	SETUP DAY		
TUESDAY	TEST 1	120,000 PPH	100% D. S. BITUMINOUS
	TEST 1A	100,000 PPH	100% D. S. BITUMINOUS
WED.	TEST 2	120,000 PPH	10% ANTHRACITE
	TEST 2A	100,000 PPH	10% ANTHRACITE
THURS.	TEST 3	100,000 PPH	20% ANTHRACITE
	TEST 3A	80,000 PPH	20% ANTHRACITE
FRIDAY	TEST 4	80,000 PPH	30% ANTHRACITE
	TEST 4A	60,000 PPH	30% ANTHRACITE

WEEK 2

MONDAY	TEST 5	120,000 PPH	100% ROM BITUMINOUS
TUESDAY	TEST 6	120,000 PPH	10% ANTHRACITE
	TEST 6A	100,000 PPH	10% ANTHRACITE
WED.	TEST 7	100,000 PPH	20% ANTHRACITE
	TEST 7A	80,000 PPH	20% ANTHRACITE
THURS.	TEST 8	80,000 PPH	30% ANTHRACITE
	TEST 8A	60,000 PPH	30% ANTHRACITE

WEEK 3

BLEND ANTHRACITE/RUN-OF-MINE BITUMINOUS
LOAD PPH TO BE DETERMINED, NORMAL PLANT OPERATIONS

Table 3

Holston Army Ammunition Plant Actual Test Runs

Week of July 20, 1987				
Monday	Setup Day			
Tuesday	Test 1	-	100,000 pph	100% D.S. Bituminous
	Test 1A	-	80,000 pph	100% D.S. Bituminous
Wednesday	Test 2	-	100,000 pph	15% Anthracite 85% D.S. Bituminous
	Test 2A	-	80,000 pph	15% Anthracite 85% D.S. Bituminous
Thursday	Test 3	-	100,000 pph	22% Anthracite 78% D.S. Bituminous
	Test 3A	-	80,000 pph	22% Anthracite 78% D.S. Bituminous
Friday	Test 4	-	80,000 pph	31% Anthracite 69% D.S. Bituminous
	Test 4A	-	60,000 pph	31% Anthracite 69% D.S. Bituminous
Week of July 27, 1987				
Monday	Test 5	-	100,000 pph	100% ROM Bituminous
Tuesday	Test 6	-	100,000 pph	22% Anthracite 78% ROM Bituminous
	Test 6A	-	80,000 pph	22% Anthracite 78% ROM Bituminous
Wednesday	Test 7	-	100,000 pph	30% Anthracite 70% ROM Bituminous
	Test 7A	-	80,000 pph	30% Anthracite 70% ROM Bituminous
Thursday	Test 8	-	100,000 pph	42% Anthracite 58% ROM Bituminous
	Test 8A	-	80,000 pph	42% Anthracite 58% ROM Bituminous
Week of August 3, 1987				
Normal Plant Operation				30% Anthracite 70% ROM Bituminous

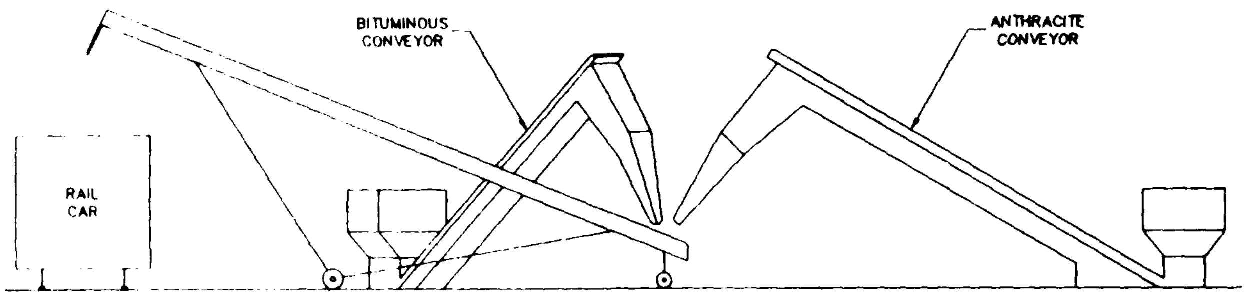

Figure 2. Coal blending apparatus.

emptied back into a railcar. This system was not designed to blend coals. To accomplish uniform blending, three mobile belt conveyors were rented and placed at the coal yard as illustrated in Figure 2. Two of the conveyors were equipped with variable-rate feeders. Anthracite was fed to one of these conveyors and bituminous to the other. Desired blend ratios were obtained by timing the volumetric flow rates from the two variable-rate conveyors onto a third common conveyor. The third conveyor loaded the coal into a railcar.

The test blend was then unloaded at the boilerhouse and run through the crusher, into a bucket elevator, and onto a tripper belt to be dumped into the bunker. During the first week of testing, a blend of anthracite and D.S. bituminous coal was burned. To avoid creating fines in the crusher, the ring roll hammers were removed from the crusher. They were replaced for the second and third weeks of testing with the ROM bituminous. Before the start of the testing program, the bunker for Boiler No. 1 was emptied and cleaned as much as possible from above. During testing, the bunker was maintained at a low level to avoid mixing different test blends.

The coal flowed by gravity to the six stoker feeders. During the 2-week test program, a service engineer from the stoker manufacturer was present to optimize stoker operations and to provide continuity between different boiler operators. Once the desired test steam load was reached in the morning and the ash bed on the grates was established, the boiler outlet oxygen would be reduced to increase efficiency while allowing for proper combustion. A total of three test runs would then be made, each lasting about 1.17 hr (the time to complete an EPA Method 5 particulate run), with 30 min between runs. During each of these runs, instrument board data and oxygen, temperature, and pressure readings were recorded every 15 min. Composite coal, bottom ash, and fly ash were sampled every 30 min. After the three runs were completed at the selected high load for that day, the steam load would be lowered to the second desired boiler load and two test runs were made at that level, with the same data collected.

4 RESULTS

Sampling

Table 4 displays the results of the stack emissions sampling and analyses of the collected ash samples for each test condition. These numbers are an average of three test runs at the higher steam rate and two test runs at the lower steam rate for a given blend. The carbon percentage given is on a by-weight basis. Particulate emissions are actually sampled on a pounds-per-hour basis and then converted to pounds per million British thermal units (MBtu) by using the "F-Factor" method as defined by EPA.[2] The "F-Factor" is a calculated value based upon a fuel analysis rather than using actual coal input. This approach must be used, by EPA regulation, for reporting. The allowable particulate emission rate for Holston AAP is 0.1 lb/MBtu.

The raw field data recorded was loaded into SAI's in-house software for analysis. This software is a compilation of the American Society of Mechanical Engineers (ASME) Power Test Code.[3] An example of the output is shown in the Appendix. The program calculates the boiler thermal efficiency using ASME Power Test Code's heat loss and input-output methods. In calculating boiler efficiency, the radiation loss and carbon loss are estimated using American Boiler Manufacturers' Association (ABMA) curves (Figures 3 and 4).

Table 5 displays the results of the sizing analysis: coal samples were taken from all five runs for each blend and then averaged for that test condition. As mentioned before, when burning anthracite and D.S. bituminous, the ring roll crusher was not used. Using an average for each test condition and stockpile, the range in coal sizing for each of the six test blends and three stockpiles is displayed in bar chart form in Figures 5 through 7. Figure 8 is a plot of the minus 1/4 in. fraction versus the percentage anthracite in the six different blends and the three stockpile samples. As demonstrated by Figures 5 through 8, the ROM bituminous was the source of fines in the anthracite/ROM bituminous blends. Because the anthracite was carefully sized, when it was blended with the ROM bituminous, it increased the fraction of correctly sized (1-1/4 in. by 1/4-in.) coal being fed to the stoker. The size of the D.S. bituminous was ideal for spreader stoker combustion.

Visual Observations

The operation of the boiler during test runs was monitored in several ways. The stack sampling, ash samples, and instrument data provided concrete, definitive numbers, which are completely objective. However, the evaluation of stoker combustion of coal is not an exact science. All the operating parameters can be the same on two different days, but result in completely different states of combustion. Much of the analysis of this test program must be done subjectively, by experts who visually judge the coal combustion process by inspecting the fuel bed and watching trends in key parameters.

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[2]Title 40, CFR, Part 60, "Standards of Performance for New Stationary Sources," Subpart C, "Emission Guidelines and Compliance Times."

[3]*Power Test Code: Steam Generating Units*, PTC.4.1 (American Society of Mechanical Engineers [ASME], New York, 1964).

Table 4

Stack Emissions and Ash Carbon Content

Coal Blend	Steam Load PPH	Particulate Emissions Lbs/MMBtu	Bottom Ash Carbon %	Fly Ash Carbon %	Mechanical Collector Carbon %
100% D.S. Bituminous	100,000	.0809	8.02	33.37	
	80,000	.2397	7.59	33.56	
15% Anthracite/D.S. Bituminous	100,000	.0888	16.58	55.70	
	80,000	.2585	17.67	45.97	
22% Anthracite/D.S. Bituminous	100,000	.0311	16.87	59.50	
	80,000	.0802	13.53	54.52	
31% Anthracite/D.S. Bituminous	80,000	.0158	16.04	51.97	
	60,000	.0432	13.34	37.05	
100% ROM Bituminous	100,000	.0083	8.04	55.77	
22% Anthracite/ROM	100,000	.0077	10.79	44.2	69.43
	80,000	.0139	14.97	44.03	60.02
30% Anthracite/ROM	100,000	.0065	16.62	35.09	71.1
	80,000	.0079	25.96	37.61	61.1
42% Anthracite/ROM	100,000	.0081	21.49	42.55	73.02
	80,000	.0203	16.98	36.50	72.11

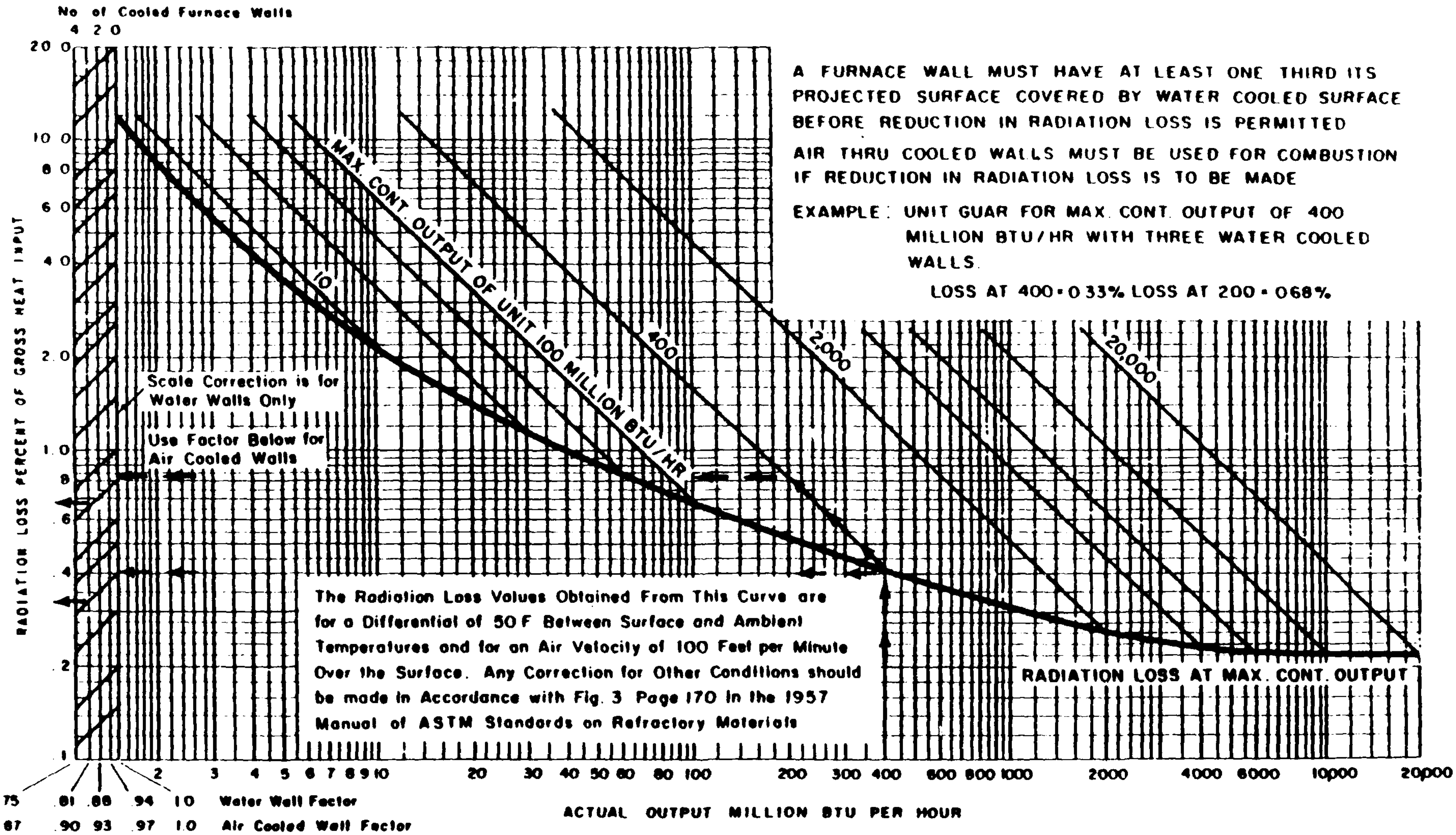

Figure 3. ABMA radiation loss curve. For MCR 160,000 pph (170 MBtu/hr): 0.42% loss. 100,000 pph (106 MBtu/hr): 0.64% loss. 80,000 pph (85 MMBtu/hr): 0.80% loss. 60,000 pph (64 MMBtu/hr): 1.07 loss. (Source: "Recommended Stoker Carbon Losses," American Boiler Manufacturer's Association. Used with permission.)

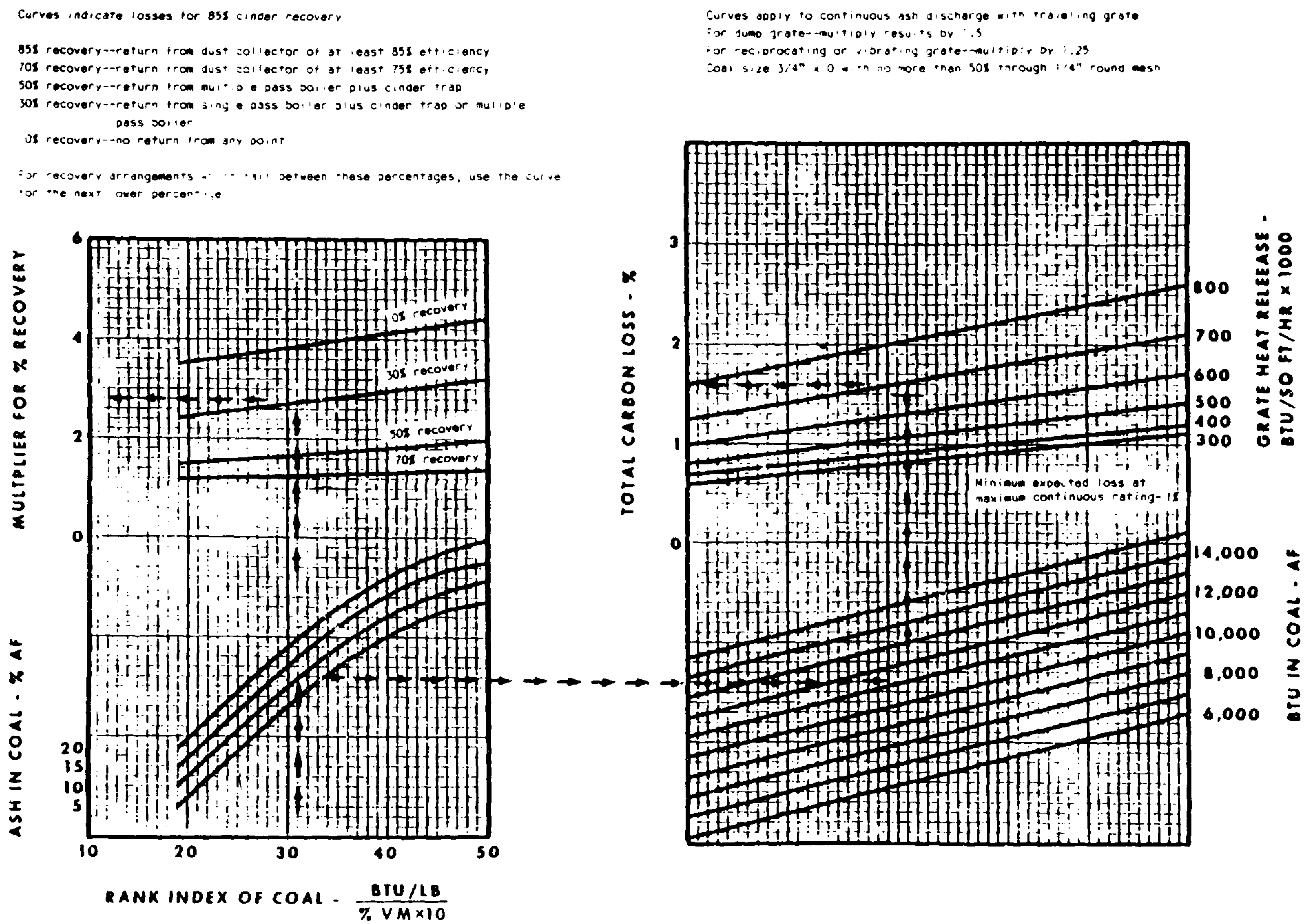

Figure 4. ABMA carbon loss curves. (Source: "Recommended Stoker Carbon Losses," American Boiler Manufacturer's Association. Used with permission.)

Table 5

Coal Sizing Results Based on Percent Retained on Screen

Screen Size	D.S. Bit./Anthracite Blends (%)					ROM Bit./Anthracite Blends (%)				
	0/100	69/31	78/22	85/15	100/0	0/100	58/42	70/30	78/22	100/0
							*	*	*	*
1-1/4 in.	0	0	0	0.6	0	0	0.4	0.1	1.8	12.3
3/4 in.	1.0	17.3	12.4	13.8	12.4	1.0	7.6	6.2	9.6	12.5
1/4 in.	91.1	68.1	74.1	71.3	61.7	91.1	57.5	51.8	49.8	30.3
#40	6.7	8.7	8.2	9.1	13.9	6.7	25.4	28.1	25.1	21.8
#10	0.8	5.3	5.2	3.2	7.4	0.8	6.2	11.3	9.9	19.9
Blank	0.4	0.6	0.1	2.0	4.6	0.4	2.9	2.5	3.8	3.2
<1/4 in.	7.9	14.6	13.5	14.3	25.9	7.9	34.5	41.9	38.8	44.90

*Ring roll crusher in operation.

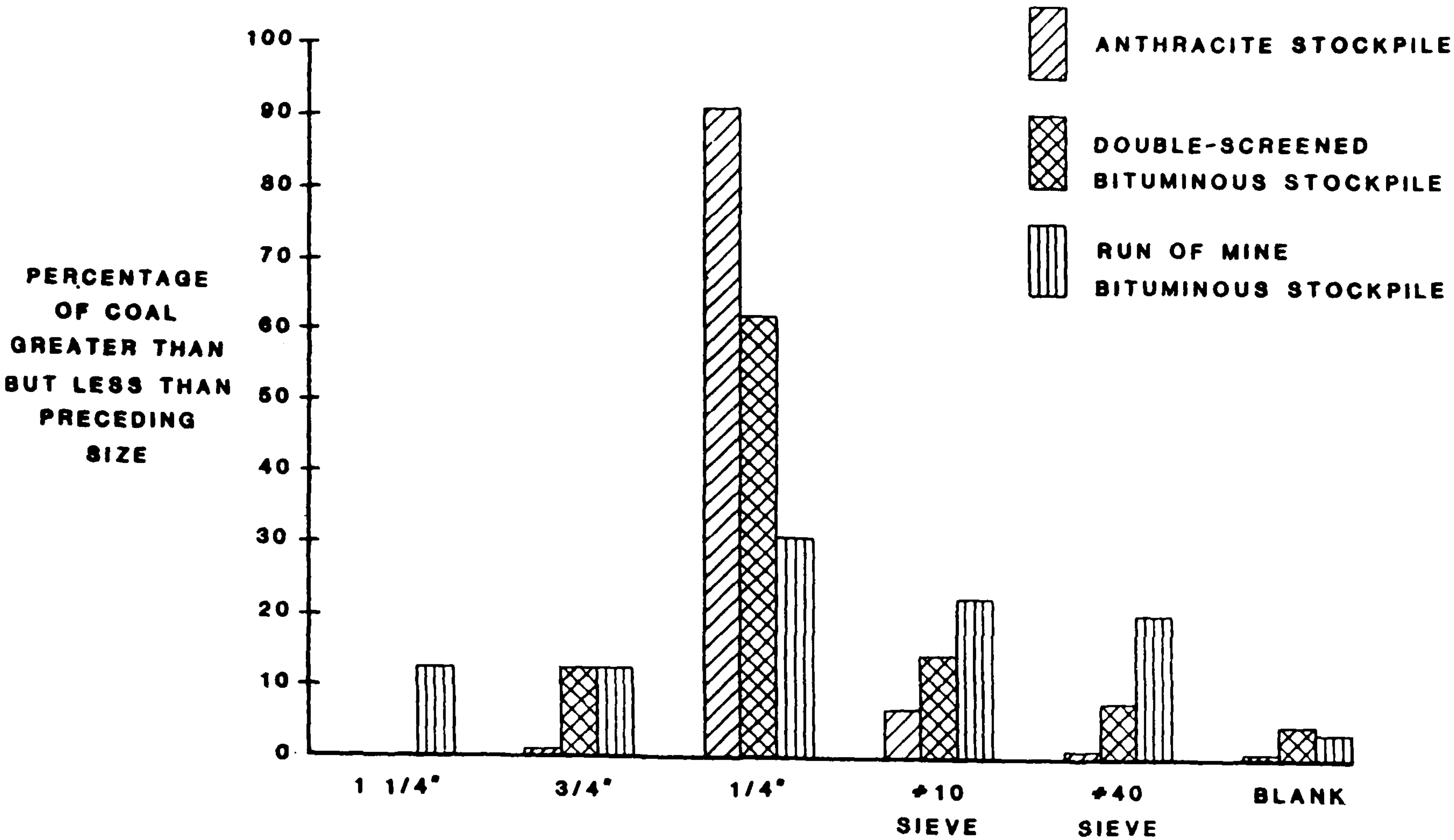

Figure 5. Coal sizing—stockpile samples.

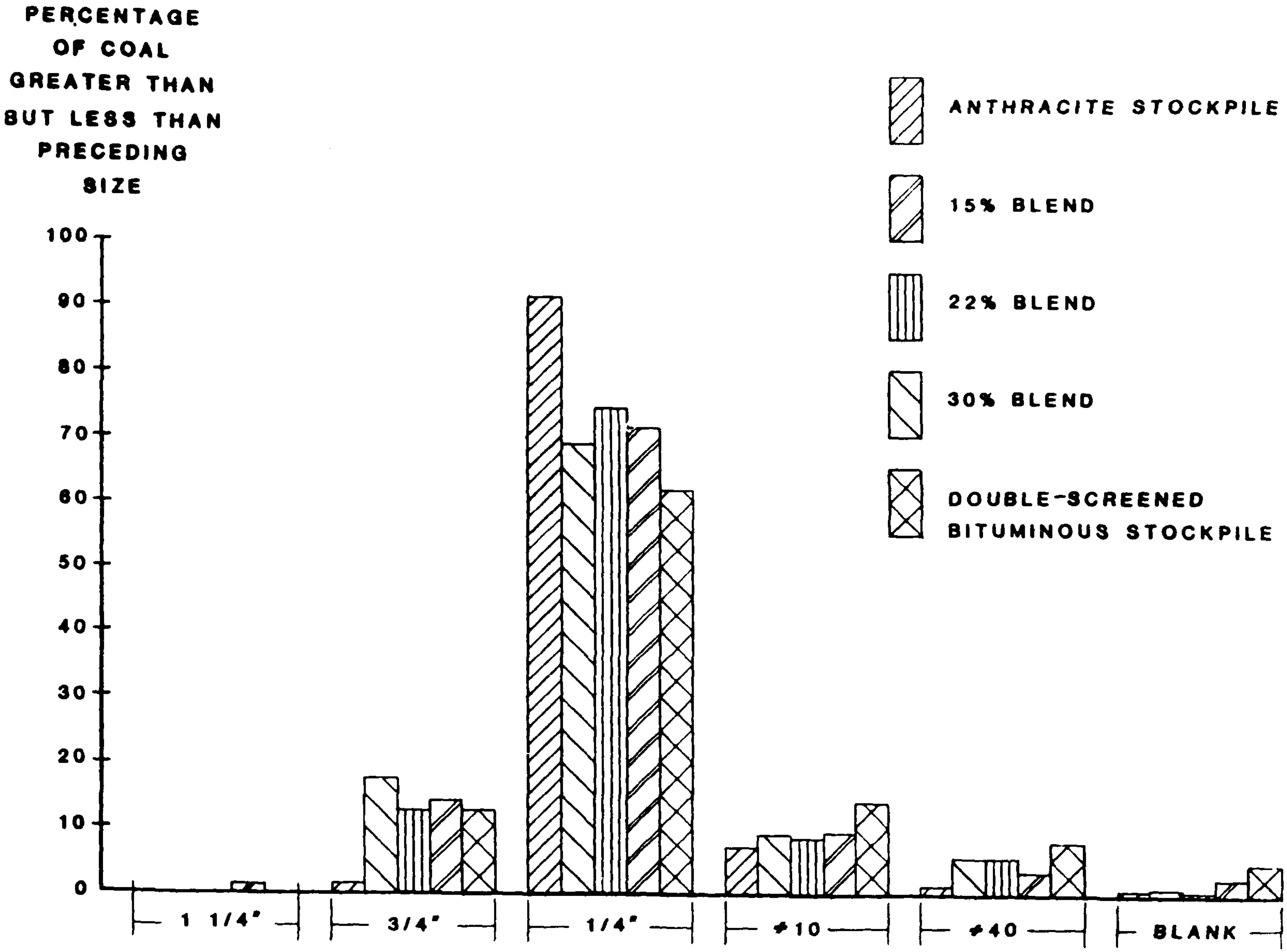

Figure 6. Coal sizing—anthracite/D.S. bituminous blends.

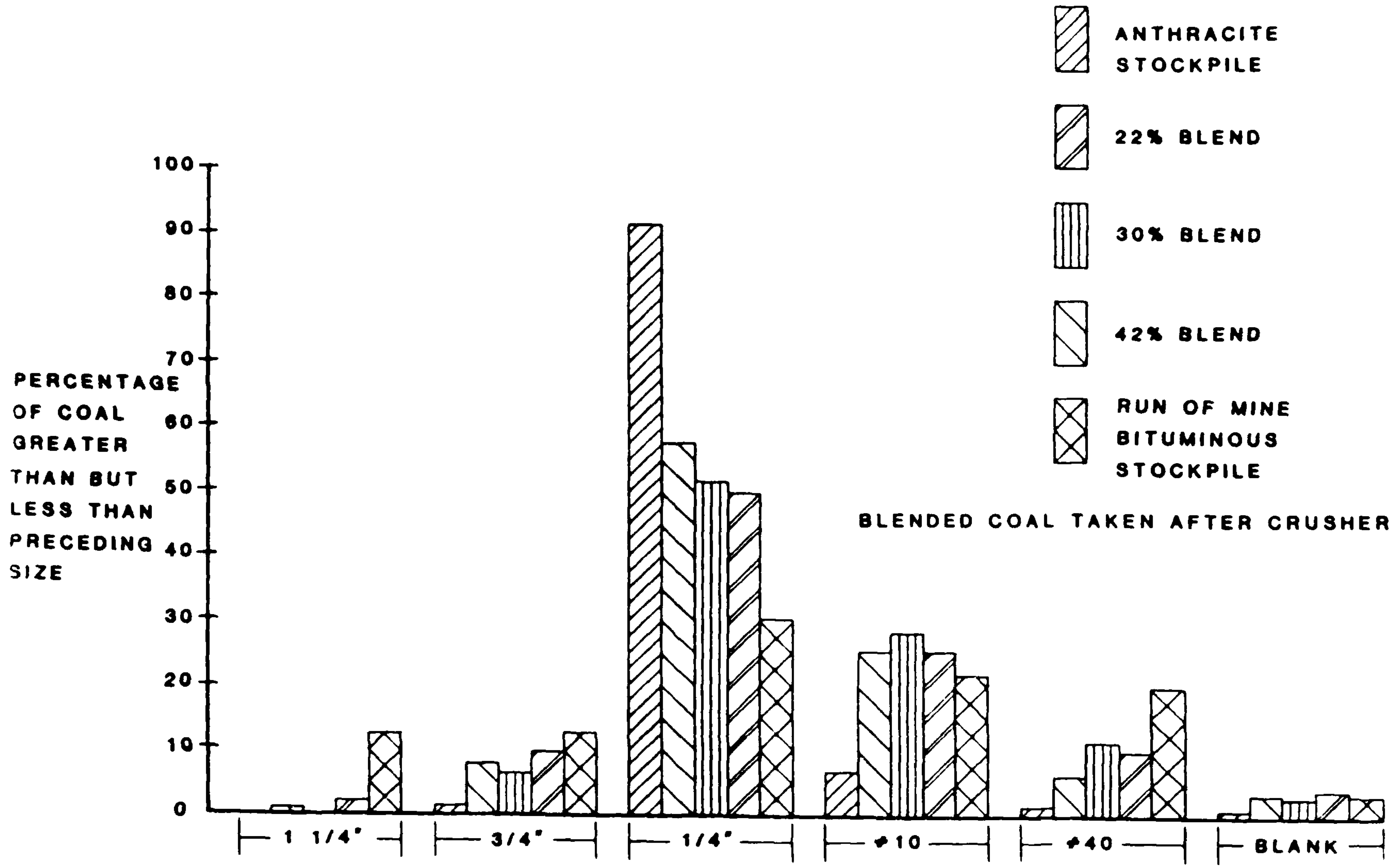

Figure 7. Coal sizing—anthracite/ROM bituminous blends.

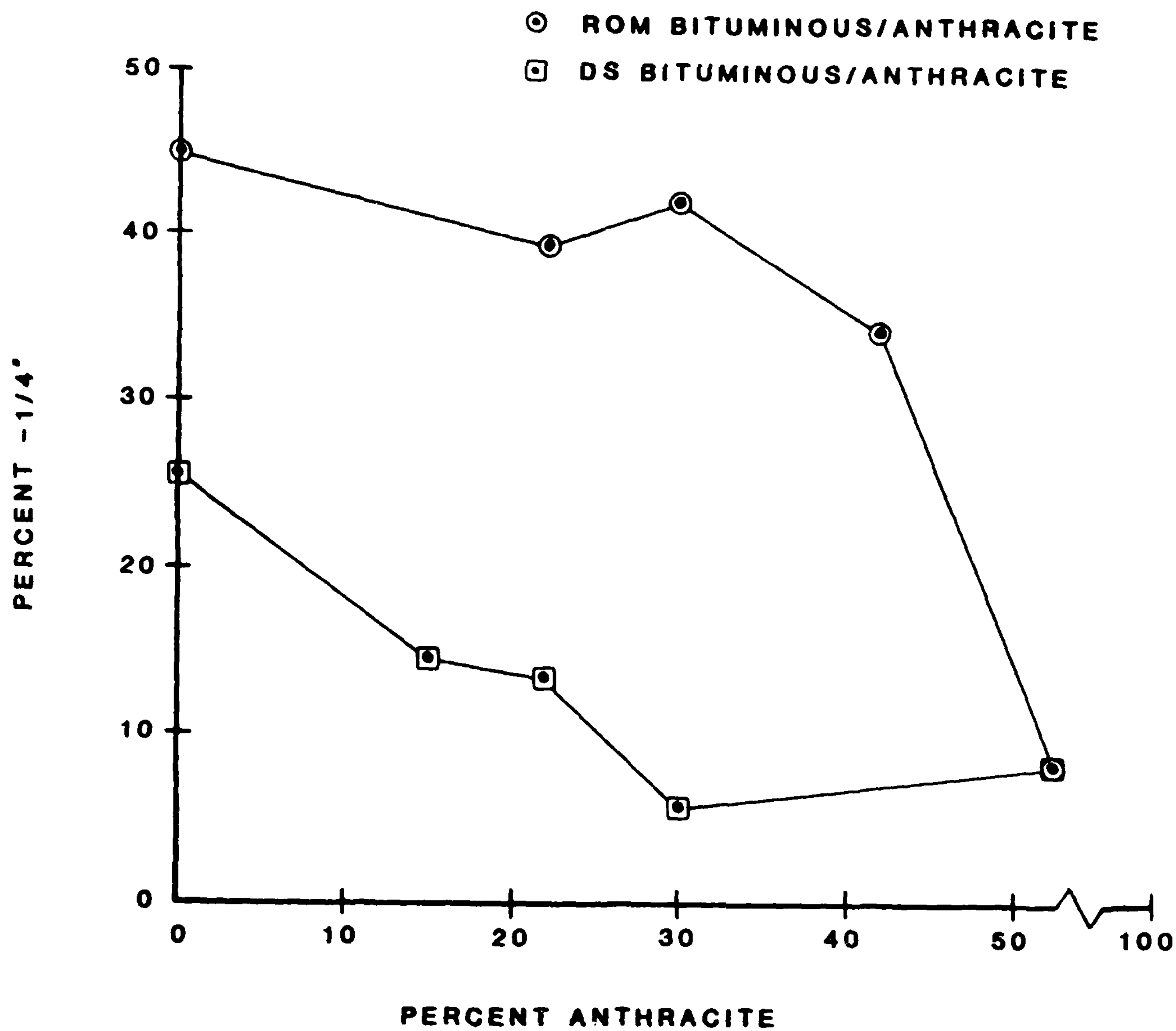

Figure 8. Coal sizing—minus 1/4 in. vs. percent anthracite.

The following observations concerning the fuel bed and boiler operations were recorded during testing.

100 Percent D.S. Bituminous

Excellent combustion with no problems. Able to run boiler oxygen at much lower than normal levels: 7 to 8 percent compared to 11 to 12 percent. Ash bed even at 4 to 6 in. through the day, with no clinkering. No change observed in the ESP performance.

15 Percent Anthracite/D.S. Bituminous

Good combustion; even ash bed of 3-1/2 to 5 in.; no clinkering; complete combustion coming off the grate. Broke a shear pin in third run, lost three feeders for 2 min. Fly ash samples from ESP appeared to be much larger and denser than normal. Spark rate in Field 1 of the ESP went from 5 sparks per minute (spm) to 40 spm. Asked maintenance to increase rapper frequency; however, they increased intensity and duration, not frequency. Recorded no increase in combustibles at boiler outlet due to the presence of anthracite. Increased boiler oxygen to 8 to 9 percent to ensure complete combustion.

22 Percent Anthracite/D.S. Bituminous

Good combustion with an even 4-in. ash bed; however, some signs of hot ash discharging from the grate. ESP spark rate at 20 spm; operating well. No changes to date in Fields 2 and 3 of the ESP. Had maintenance increase the frequency and duration of rappers and decrease the intensity to account for the expected higher carbon fly ash from the anthracite. Oxygen at 8 to 9 percent.

31 Percent Anthracite/D.S. Bituminous

Good combustion with an even 4-1/2-in. ash bed. Still a small amount of burning material discharging from grate; however, no clinkers present. No segregation of coal in bunker apparent at feeders; uniform feed across grate. Ran oxygen higher at 9 to 11 percent. Spark rate in Field 1 consistent at 30 to 40 spm. Secondary amps acceptable at 70 to 80 mA.

100 Percent ROM Bituminous

Completed only two of the planned three runs due to severe lightning storm in area. Good combustion, with a 4- to 5-in. ash bed. No clinkering or burning coming off grate. Coal sizing during the two runs much larger than expected. Possibly the fines from the center of bunker were burned during the weekend, with the outer coarse material now coming through. Secondary amps in Field 1 down from the run of the 31 percent anthracite/D.S. bituminous blend; spark rate same at 30 to 40 spm. Seven percent oxygen during runs.

22 Percent Anthracite/ROM Bituminous

Fair combustion, with a 4-in. even ash bed. Clinkers forming at side of wall headers; coal feed contained fines, resulting in some but not excessive piling. Secondary amps returned to 70 to 80 mA in Field 1; no change in spark rate. Good oxygen level at 6 to 7.5 percent. Perhaps oxygen should have been run a

little higher to help prevent clinkering. Still, fairly easy boiler operation if clinkering controlled.

30 Percent Anthracite/ROM Bituminous (Lab Conditions)

Poor combustion all day. Coal feed had excessive fines, resulting in poor bed distribution and uniform clinkering across bed. Started with a 5-in. ash bed and 6 percent oxygen; tried to thin bed down to 3 in. with 9 percent oxygen, but never stabilized. ESP still performed well, acceptable current and spark rate.

42 Percent Anthracite/ROM Bituminous

The No. 1 hopper in the ESP plugged overnight. Had to be dug out. Spark rate was 80 spm in the morning prior to blowing soot. After the operator blew soot, the spark rate went off scale at 100 spm and did not return. The automatic voltage regulators were not working properly. Had maintenance switch the controls to manual to back off on the voltage and brought the spark rate back into range. Wanted to increase rapper frequency but was already at maximum. Adjusted ESP controls to minimum setback and lowered the primary amps upper limit. With these adjustments, the ESP was returned to automatic. Combustion was again poor; excessive fines were piling in front of the feeders, creating massive clinkers and poor bed distribution. Grates were speeded up and the oxygen increased. This resulted in fair combustion during the last two runs. The adjustments made to the ESP in the morning helped only temporarily; secondary current was often zero and the spark rate off scale. To confirm whether it was a mechanical problem, Field 1 was shut down between load changes. Within 10 min Field 2 was experiencing the same problems.

30 Percent Anthracite/ROM Bituminous (Plant Conditions)

During the third week of testing, under normal plant operating conditions, no major problems were noted. The ash bed was kept under 4 in. and the oxygen was at 10 percent and above. Clinker formation was not a problem. At lower steam rates, 60,000 to 70,000 pph and below, it was observed that the volume of ash was much greater than normal. It seemed that, at the lower loads, the furnace was too cold to combust the low-VM anthracite. Field 1 of the ESP continued to have high spark rates and low secondary amps; however, Fields 2 and 3 were unaffected.

During the 3 weeks of testing, it was noted that 90 percent of the fly ash removed by the ESP was in the first field, compared to 9 percent in the second field, and less than 1 percent in the third field.

5 ANALYSIS

Emissions

The allowable EPA particulate emissions limit for Holston Army Ammunition Plant is 0.1 lb/MBtu. Of the 15 tests conducted, two exceeded the limit, the second and fourth tests (Table 4). In reviewing all the data and observations, the only explanation found for why these two tests exceeded the limit is that scale flaked off the stack or breaching walls and was caught by the particulate probe. It is common for a boiler just returned online or operating at substantially higher than normal loads to have scale flake off of the breaching and stack for several days after start-up. The boiler used for the test had only recently been placed online and was then operated at levels higher than normal, which validates the above explanation.

To correlate the stack emissions and the conditions of the stoker and boiler, several graphs were made. Figure 9 shows a plot of the particulate emissions vs. the percentage anthracite in the coal blend using both D.S. bituminous and ROM bituminous. It was expected that the higher the anthracite content, the higher the stack emissions would be. As seen, this correlation was not evident in the data collected. This graph does not include the second and fourth tests just discussed, since it is believed that these two runs are erroneous. It is assumed that data from the tests give inaccurate emissions readings due to the boiler being operated at a higher-than-normal load.

For all of the tests conducted, an attempt was made to operate the boiler as consistently as possible. Thereby, changes in the boiler performance could be attributed to the different coal blends. However, to maintain an efficient combustion process, some changes were mandatory to compensate for the actual stoker conditions. Figure 10 plots stack emissions vs. the percentage oxygen at the boiler outlet. For a well operated boiler, with good coal and no large air leaks, the oxygen should be 5 to 6 percent at 90 percent of its design MCR. At lower steam loads, a higher oxygen is needed, up to 10.5 percent at 25 percent of MCR. An increase in excess oxygen will lower the boiler efficiency, so the minimum excess oxygen that will allow the boiler to continue operating correctly is used. This plot shows that there was sufficient air for combustion since no correlation is seen between emissions and oxygen as would be expected if the furnace were oxygen-starved. In addition to adjusting the oxygen supply, it was important to attempt to maintain an even ash bed throughout the test. If the bed is too thin, hot spots can occur. If the bed becomes too thick, it will smoke and clinkers will form. Clinkering can also be caused by an excessive amount of fines. Using a thinner fuel bed can help to reduce the amount of clinkering. The effects of these adjustments in the present tests were noted in the observations in Chapter 4.

Electrostatic Precipitator

To achieve the maximum efficiency in the ESP, the voltage used must be the highest obtainable without causing sparking between the electrode and collecting plate. This voltage, where sparking occurs between the negatively charged electrode and the positively charged collecting plate, is known as the threshold voltage. Once the voltage is increased beyond the threshold voltage, the sparking rate increases, destroying the corona effect and allowing more particles to leave the ESP uncollected. This sparking is also a potential cause of fires and explosions. So it was attempted to keep the sparking rate, indicated as spm, to a minimum to achieve maximum performance.

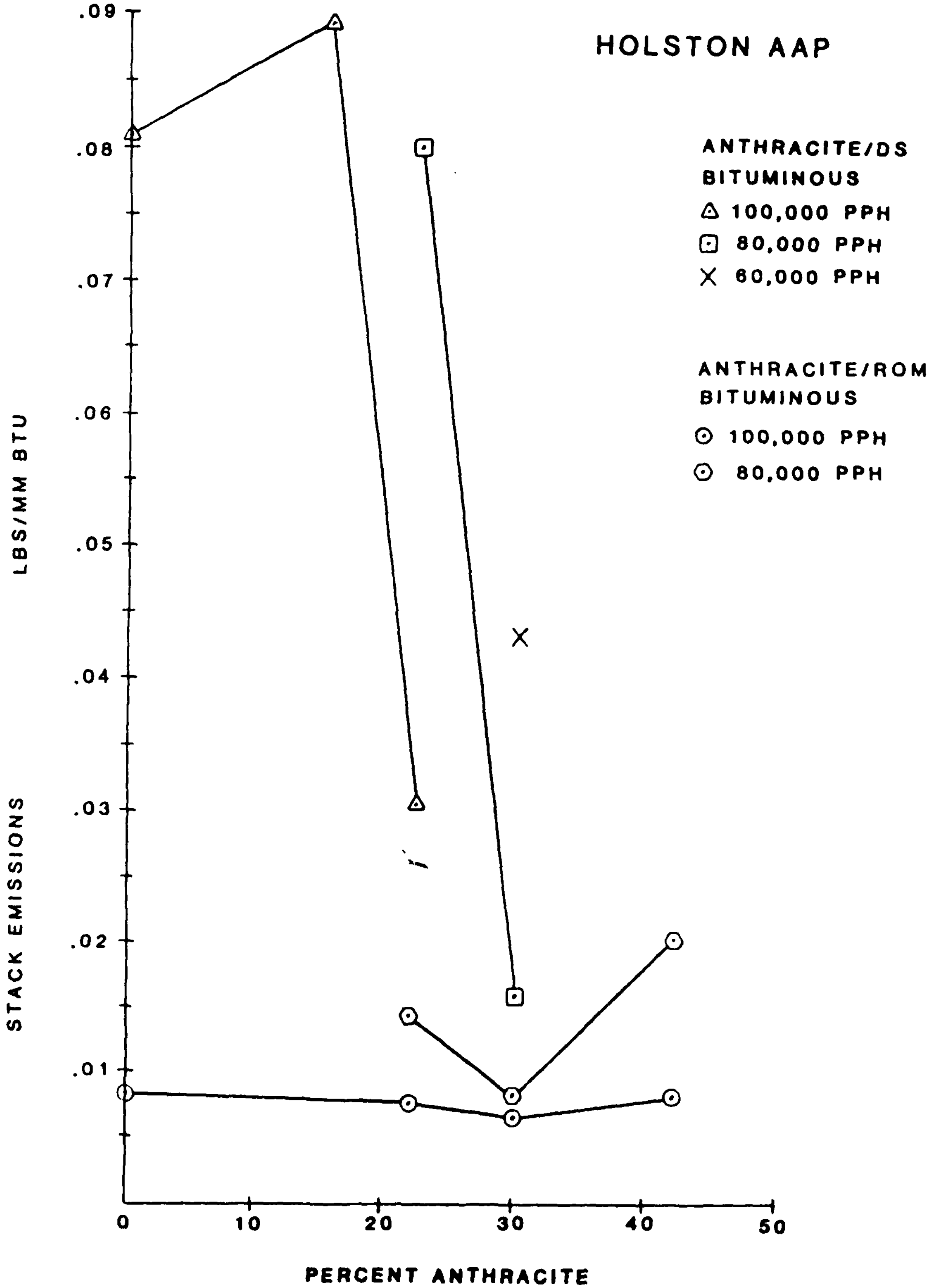

Figure 9. Stack emissions vs. percent anthracite.

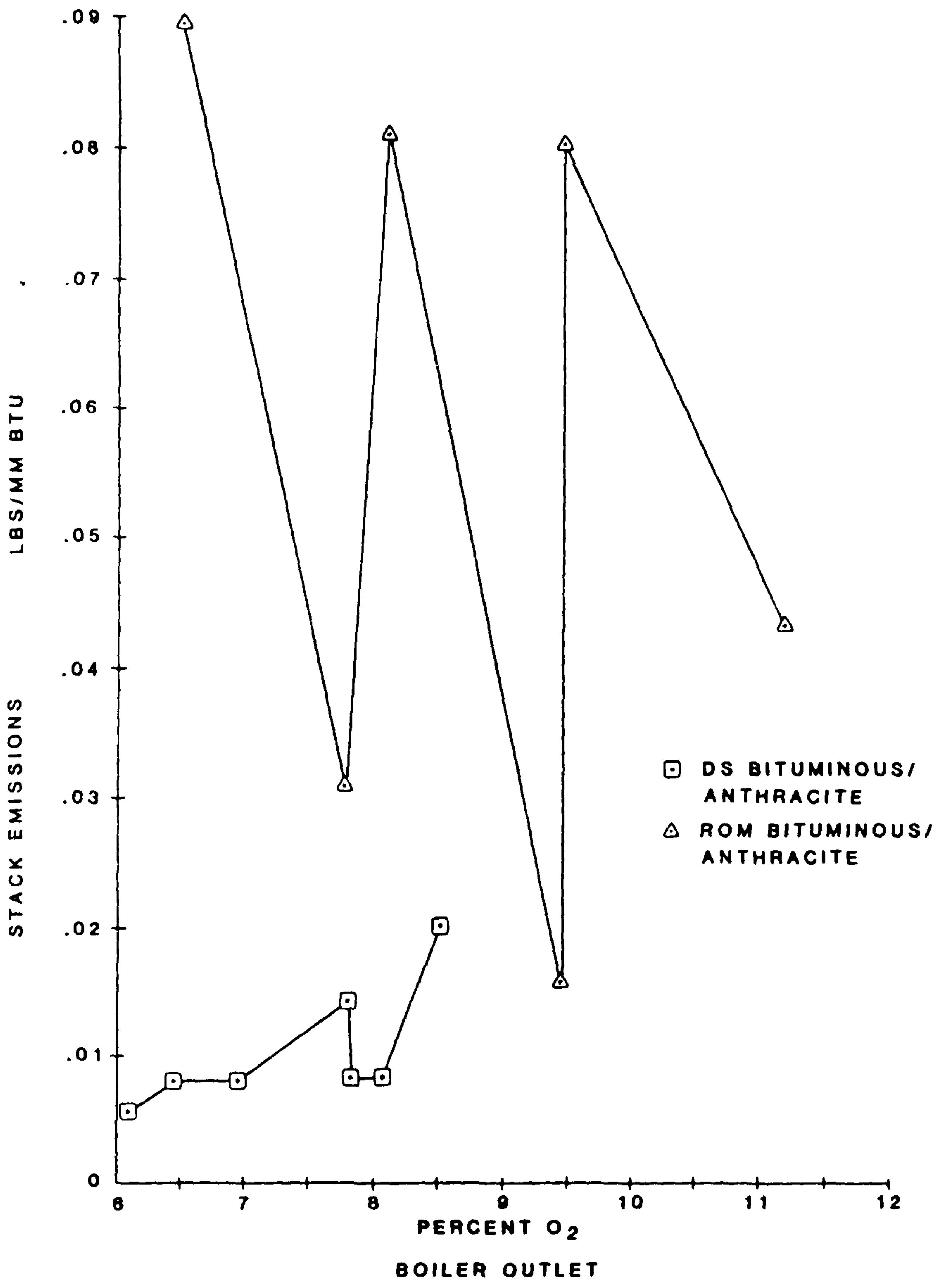

Figure 10. Stack emissions vs. percent oxygen at boiler outlet.

To evaluate the performance of the ESP, Figures 11 through 14 were prepared. With an ESP, higher secondary voltages and currents result in a higher potential between the collection plates and the wires, thereby increasing the collection efficiency. However, as shown in Figures 11 and 12, no correlation exists for data collected between stack emissions and secondary voltage or current in Field 1 of the ESP.

The higher the carbon content of a fly ash, the lower its electrical resistivity. Lower resistivity lowers the threshold at which arcing will occur between the plates and wires, reducing the voltage and the collection efficiency. Figures 13 and 14 show the percentage carbon (by weight) in fly ash samples taken from the hopper of Field 1 of the ESP vs. the secondary voltage and current in Field 1. The expected correlation can be seen for the D.S. bituminous data in both plots, although it is not evident with the ROM coal.

Though, as a whole, the data collected cannot be correlated to stack emissions, Figures 13 and 14 do weakly support the theory that higher carbon fly ash reduces ESP performance as measured by secondary voltages and currents. Figure 15 displays the carbon content of ESP fly ash, mechanical collector fly ash, and bottom ash vs. percentage anthracite in the coal blend. The data for the bottom ash and mechanical collector fly ash follows the expected pattern; the higher the anthracite percentage, the higher the carbon content. The correlation is also demonstrated by the D.S. bituminous coal data for the ESP fly ash. However, once again, the ROM bituminous does not fit the correlation.

Thermal Efficiency

Estimated carbon loss used in SAI's in-house software for calculating thermal efficiencies is taken from an ABMA curve as previously referenced in Figure 4 (Chapter 4). As can be seen, the estimated carbon loss depends on five factors: coal rank index, percentage ash in coal, coal heating value, boiler grate heat release rate, and boiler configuration. By blending anthracite with bituminous for Holston AAP, of the five factors, only the rank index of the coal is affected. The rank index, as shown in Figure 4, is equal to the heating value of the coal divided by the percentage volatile matter in the coal. Thus, by blending low-volatile-matter anthracite with high-volatile-matter bituminous, the rank index is higher. Figure 16 displays actual fly ash carbon content vs. percentage thermal efficiency loss due to unburned carbon. Again, the D.S. bituminous data follows the expected pattern while the ROM data slope is opposite.

Summary

The results of the test program conducted at Holston AAP were both successful and disappointing. The primary objective was accomplished; the tests demonstrated that an anthracite-bituminous coal blend could be combusted in a spreader stoker traveling grate boiler designed for high volatile bituminous coal only. But the tests were disappointing in that the data collected during the testing was inconclusive regarding key parameters. Combustion of the anthracite/D.S. bituminous coal blends was, by all visual indications, an order of magnitude better than combustion of the ROM bituminous, which had all the problems associated with fine coal. However, the stack emissions for the ROM blends were an order of magnitude better than the D.S. blends.

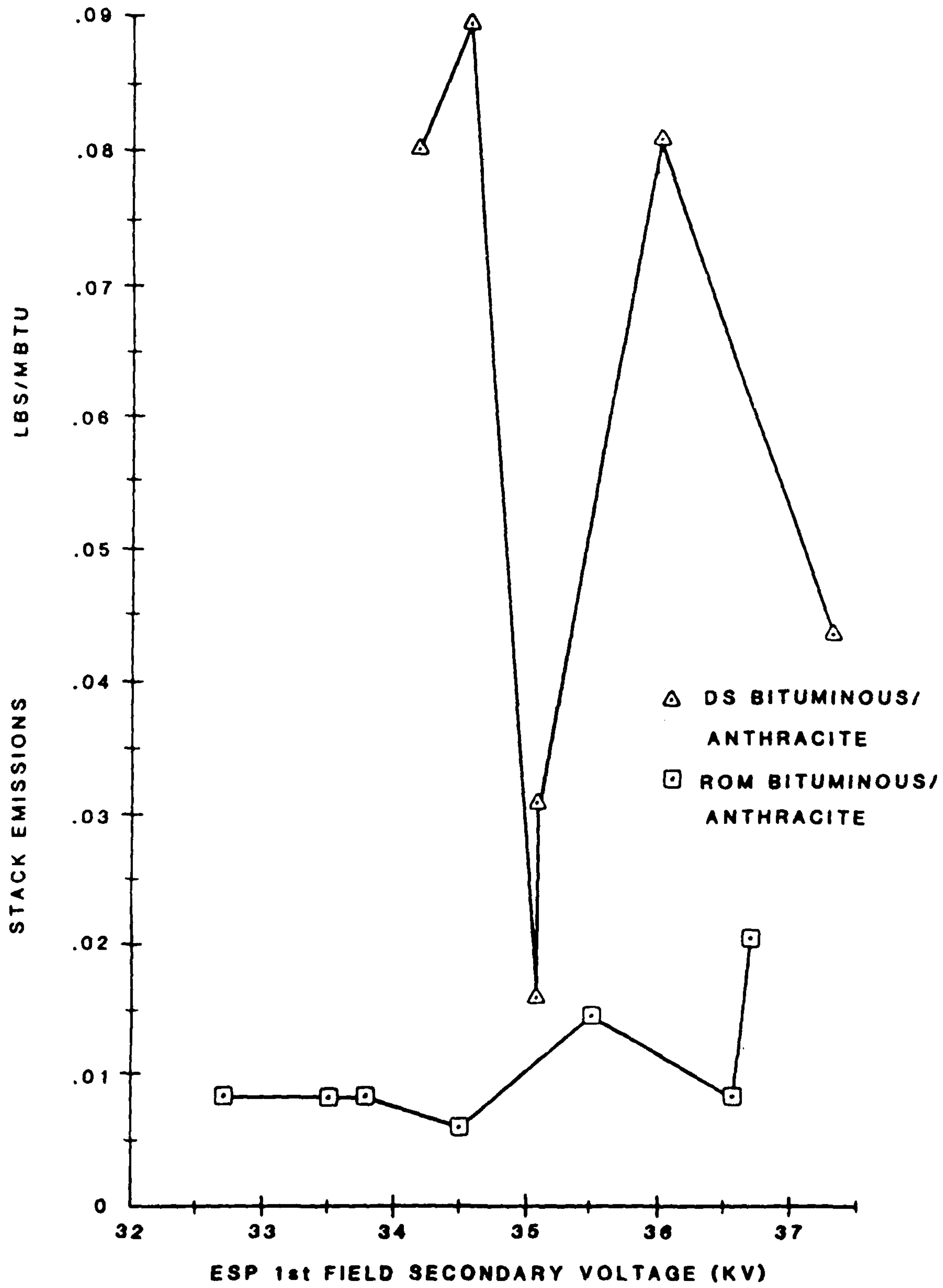

Figure 11. Stack emissions vs. ESP field 1 secondary voltage.

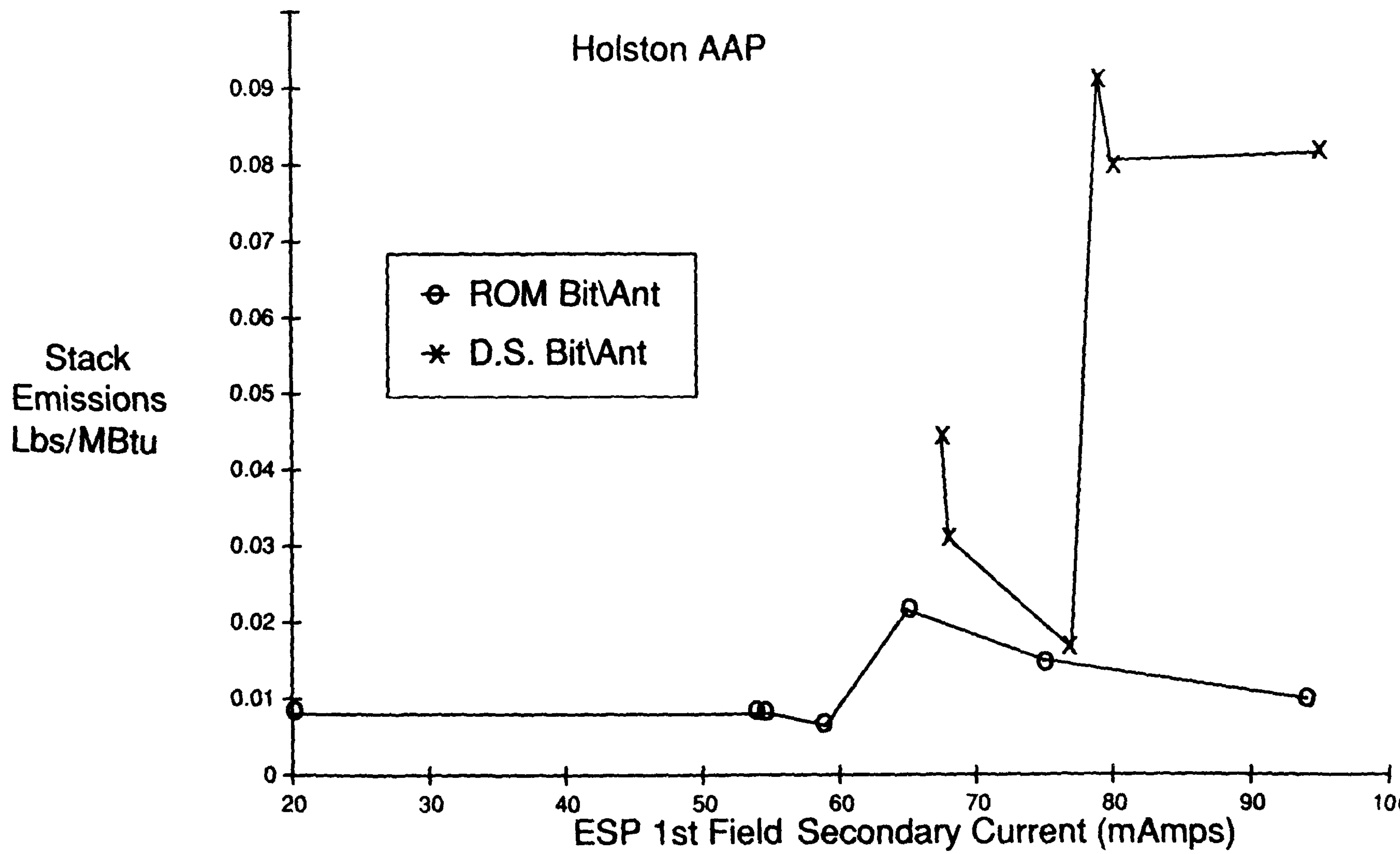

Figure 12. Stack emissions vs. ESP field 1 secondary current.

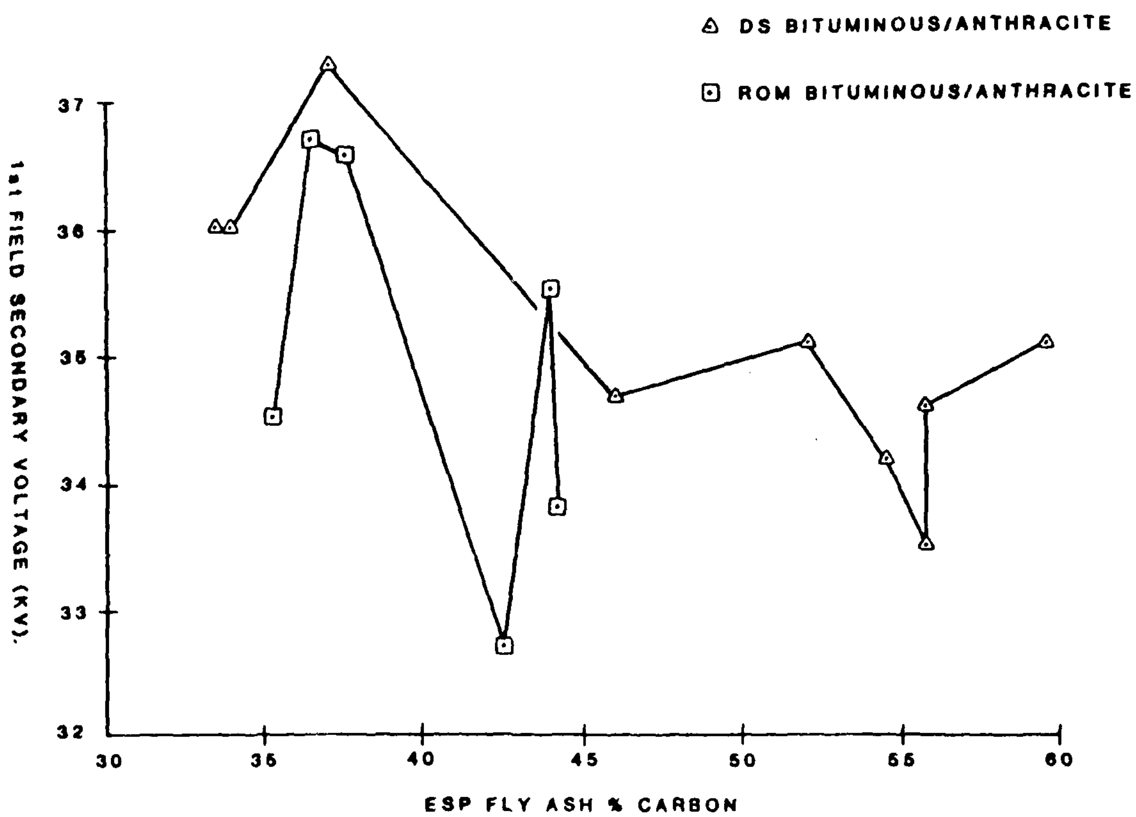

Figure 13. ESP secondary voltage vs. percent carbon in ESP fly ash.

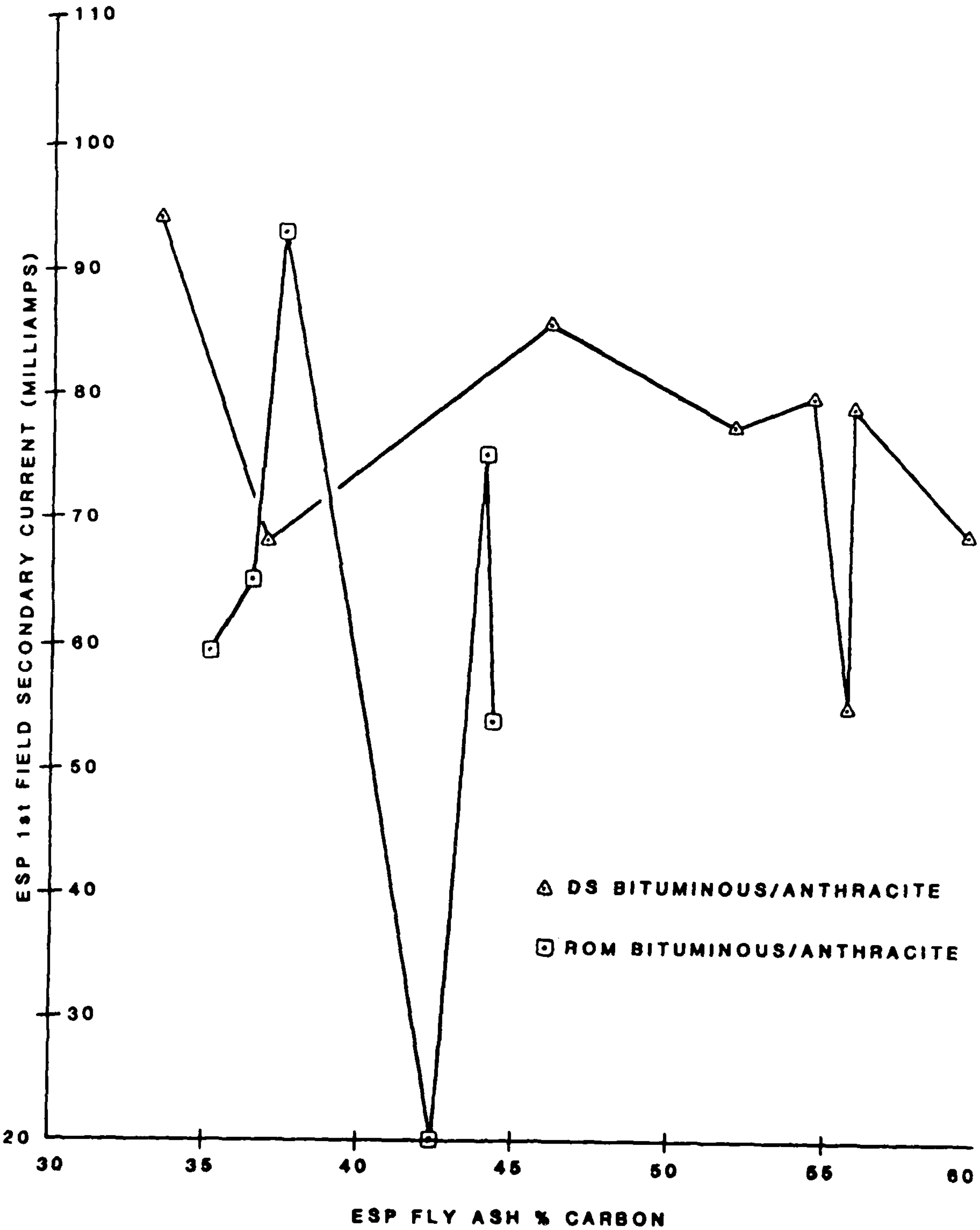

Figure 14. ESP secondary current vs. percent carbon in ESP fly ash.

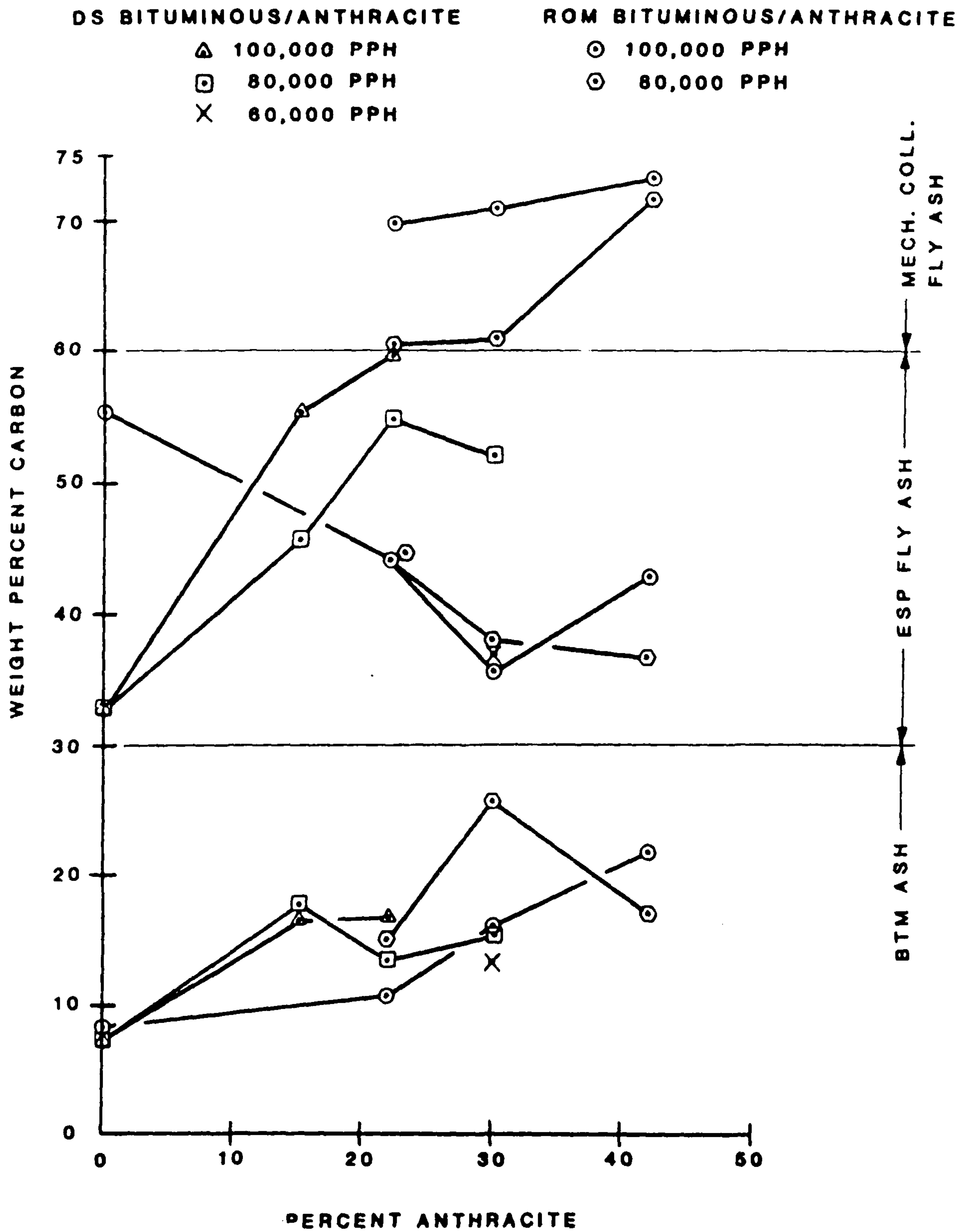

Figure 15. Ash weight percent carbon vs. percent anthracite.

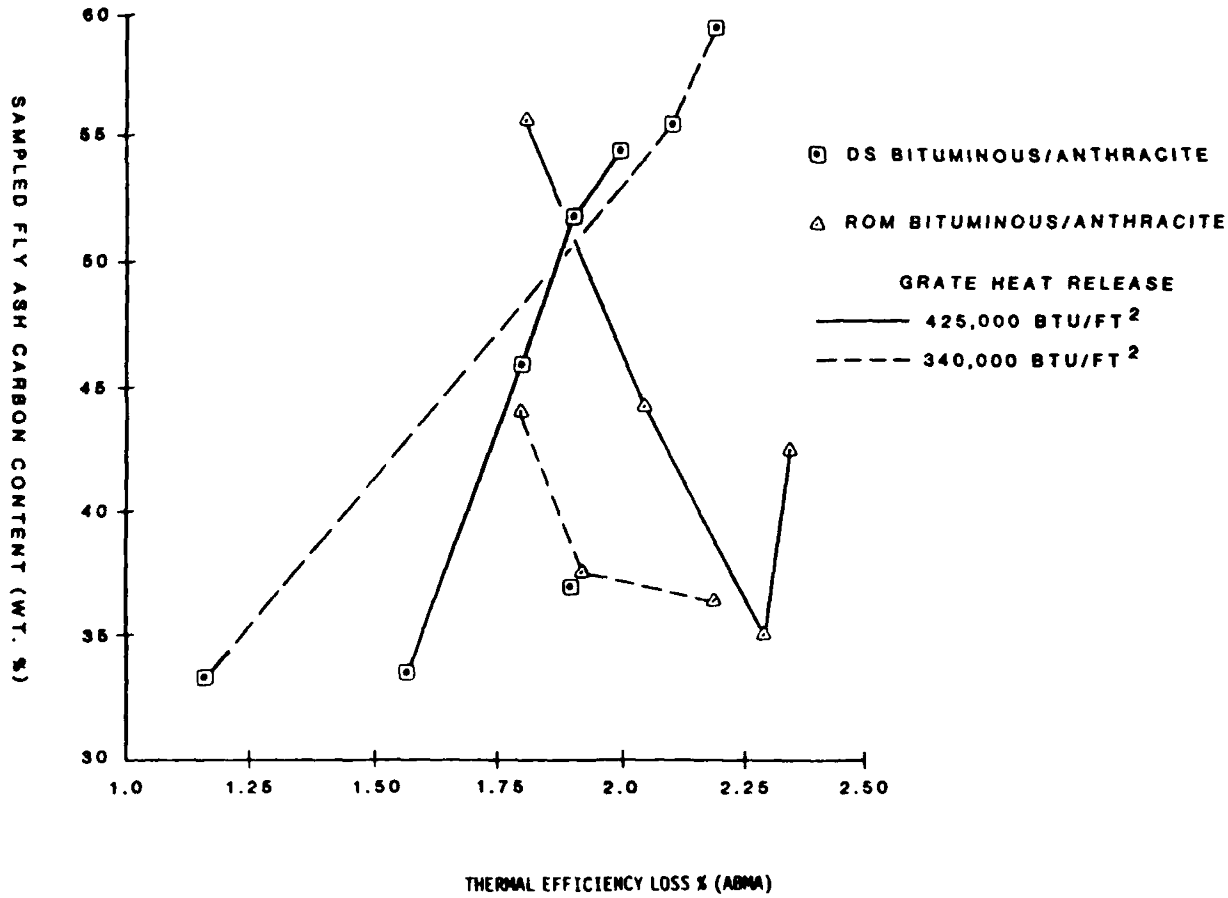

Figure 16. ESP fly ash weight percent carbon vs. ABMA thermal efficiency loss.

The fly ash carbon analysis did not produce the expected results. The three base load tests with 100 percent D.S. bituminous and ROM bituminous (Tests 1, 1A, and 5) resulted in the expected pattern (considering the size distribution of the two coals): 33.4, 33.6, and 55.7 percent carbon by weight, respectively. The fine ROM bituminous resulted in a high carbon fly ash. However, the results of the blend runs with both coals displayed no correlation either to the percentage anthracite in the blend or even to the size of the two bituminous coals. Although the objective data showed few definite trends, there were clear subjective correlations with operational parameters (e.g., bed thickness, oxygen, sparks per minute), as discussed in **Visual Observations**, Chapter 4.

If further testing is conducted with anthracite-bituminous coal blends at Holston or another Army facility, two additional tasks should be incorporated into the test program. First, the boiler to be tested must be able to operate at its MCR. At Holston, the steam loads could not be varied significantly enough to evaluate the combustion in regard to the grate heat release rate. This is especially true at the upper rates, where only a 425,000 Btu/sq ft/hr rate could be obtained, while at a boiler MCR of 160,000 pph, the grate heat release rate would have been 680,000 Btu/sq ft/hr. At such a high release rate, with its associated shortened furnace retention time, the anthracite-bituminous coal blend may not have performed as well. This could be a critical factor at other Army facilities. The second task that should be included is to perform a complete mass

balance for several test runs to accurately determine the amount of unburned carbon. While the use of ABMA curves has proven reliable for bituminous coal alone, it is not as accurate for an anthracite-bituminous blend. Particulate sampling in the future should be performed ahead of the ESP/baghouse: by performing mass balance on several runs, with particulate sampling ahead of the final compliance equipment, a correlation can be developed relating particulate loading to the volumes of ash of unburned carbon.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The tests reported here successfully demonstrated that an anthracite-bituminous coal blend can be combusted in a spreader stoker boiler designed for high-VM bituminous coal, as long as the unit is properly operated and maintained and the blended coal feed is homogeneous. The procedure developed for blending was satisfactory.

During the 3-week testing period at Holston AAP, no technical problems were found that would prevent the long-term combustion of anthracite at the Area B Boilerhouse or any other similar Army boiler. A blend of 30 percent anthracite and 70 percent bituminous can be fired without difficulty under normal plant operations with a turndown of 3:1 of boiler capacity (55,000 to 160,000 pph at Holston, with an actual upper limit of 120,000 pph). However, at lower loads (below 55,000 pph at Holston AAP) furnace temperatures may be too low to sufficiently combust the anthracite, resulting in unacceptable carbon losses and excessive volumes of ash. The following are additional observations based on the test experience:

- The homogeneous prepared blend of anthracite and bituminous coal displayed no tendency to segregate during coal handling.
- As evidenced by visual observations and the condition of the ash bed (although stack emissions and ash carbon analyses did not support this) the anthracite-D.S. bituminous coal blend combusted significantly better than the blend using ROM bituminous, due solely to coal sizing.
- When combusting an anthracite-bituminous coal blend, the ash bed should be kept approximately 25 percent thinner than it would be with bituminous coal only to avoid clinkering.
- Holston AAP's current use of ROM bituminous coal and the use of a Knittel ring roll crusher generates excessive fines that are unacceptable for spreader stoker combustion due to the clinkering problems they create.
- Holston AAP's existing flue gas particulate removal equipment is completely adequate to reduce particulate emissions from an anthracite-bituminous coal blend to well below allowable EPA limits.
- In general, the boilers at the Holston AAP Area B Boilerhouse can be operated at 3 to 6 percent lower oxygen levels than present, resulting in an increase of up to 5 percent in boiler efficiency if reliable oxygen meters were installed at the boiler outlets.
- To prepare a homogeneous anthracite-bituminous coal blend, the system used at Holston AAP was adequate for testing purposes; however, for any long-term blending, a system must be devised to eliminate the double handling of coal.

Recommendations

- Since 100 percent MCR was not reached, further testing would be appropriate. Included in the testing should be tests at 25 percent of boiler capacity to

determine if combustion temperatures are adequate. Also, a complete mass balance should be physically performed for several tests to quantify the ash streams from the three sources: bottom ash, mechanical collector fly ash, and ESP fly ash.

- Holston AAP should purchase D.S., stoker-sized coal. Eliminating the Knittel ring roll crusher, which generates excessive fines, will not reduce the excessive fines (45 percent minus 1/4 in.) sampled in the stockpile by USA-CERL.

- Oxygen meters should be installed at the boiler outlet on all boilers. Oxygen is the single most important parameter under a boiler operator's control.

- The overfire air system should be modified to supply air at a minimum pressure of 30 in. of water to the boiler for improved combustion.

- Boiler No. 1 and the mechanical collector should be smoke-tested to check the integrity of the refractory and casing in the boiler and the condition of the mechanical collector tubes and tube sheets.

Two options are recommended for future burning of anthracite coal blends at Holston AAP. For long-term burning of anthracite, the existing coal handling system should be used. Holston AAP is currently constructing a new coal handling system in the Area B Boilerhouse which is completely independent of the existing system. The new system will be operational by Fall 1988. Holston Defense Corporation stated that the existing system will be maintained. Anthracite coal could be delivered by rail and unloaded directly to the bunker or stored at the existing coal yard. The only modification needed to the existing coal unloading system in the boilerhouse would be removing the ring roll hammers from the crusher to allow the coal to pass through. The flow of anthracite could be controlled with a simple guillotine gate arrangement initially set to provide the desired flow rate. The bucket elevator would discharge onto the bunker distribution conveyor, where the anthracite would mix with bituminous coal discharging from the new BC-2 conveyor. If the proper blend ratios cannot be achieved with this arrangement, a new variable-speed belt conveyor with a weigh scale and a motor-operated slide gate could be installed in the existing handling system in the tunnel under the unloading hopper. The anthracite feed rate would then be controlled from a signal originated from the weigh scale on BC-2, which would monitor the bituminous feed rate going to the bunker (see Figure 17). This option would have the following estimated cost:

	Materials ($)	Labor ($)
Belt Conveyor (20 ft)	10,000	5,000
Weigh Scale and Controller	8,500	2,000
Retort Gate and Hopper Modifications	5,000	5,000
Total:	23,500	12,000

For short-term burning of anthracite prior to the completion of the new coal handling system, the blending arrangement used during the testing program would be suitable. The cost to lease such equipment for 1 year would be $55,500.00, at the end of which time Holston AAP would own the equipment (since the only arrangement possible was lease-to-buy).

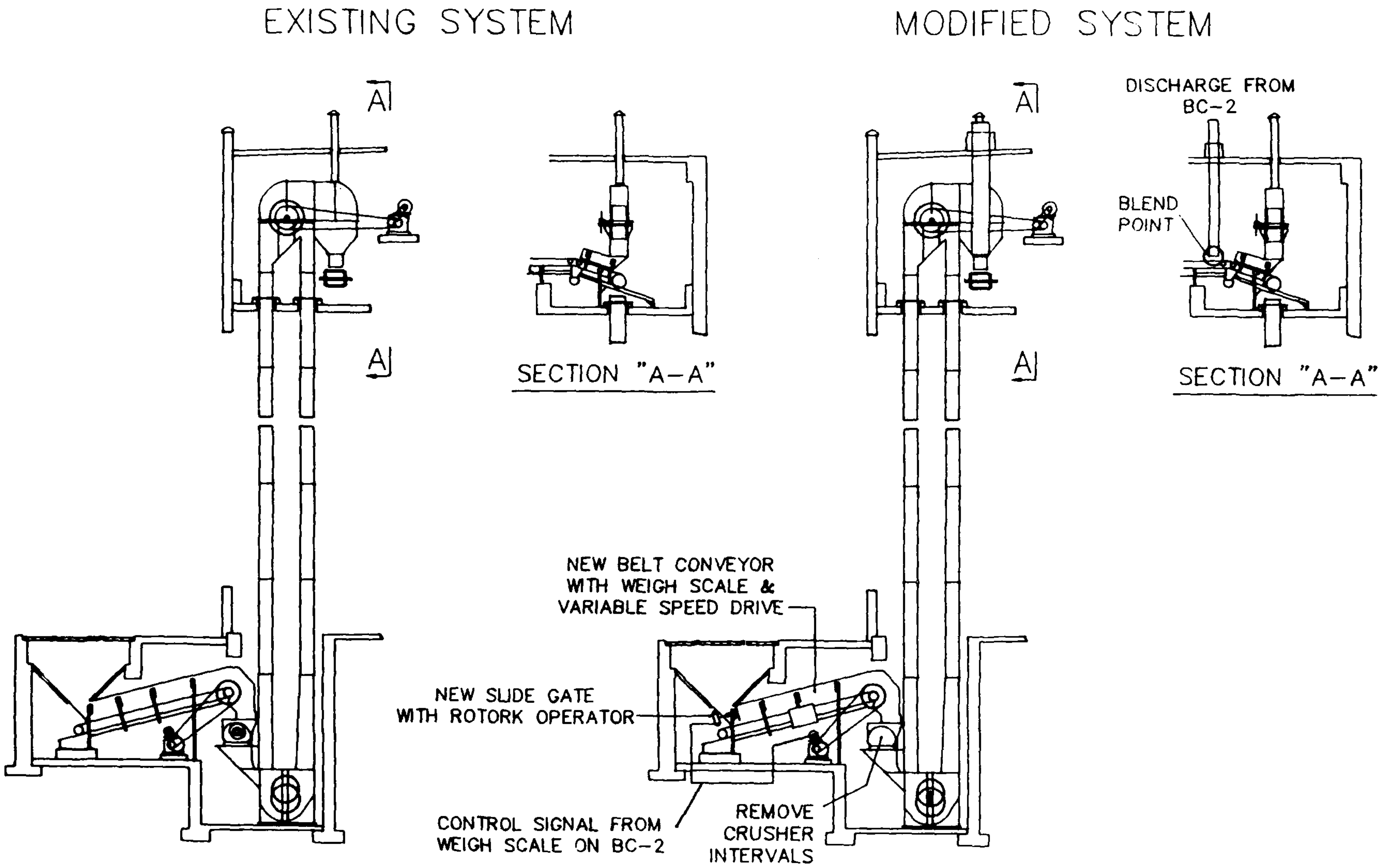

Figure 17. Conceptual modified coal handing system.

METRIC CONVERSION FACTORS

1 short ton	=	2000 lb = 907.1 kg
1 psig	=	6.895 kPa
1 °F	=	(°C x 1.8) + 32
1 lb	=	0453 kg
1 Btu	=	1.055 kJ = 252 cal
1 in.	=	2.54 cm
1 mi	=	1.609 km
1 sq ft	=	0.0929 m^2

APPENDIX:

EXAMPLE OUTPUT OF SAI's BOILER EFFICIENCY CALCULATION SOFTWARE

A software program developed by SAI calculates boiler thermal efficiency using input-output and heat loss methods from the ASME Power Test Code.[4] Radiation loss and carbon loss are estimated using ABMA curves (Figures 3 and 4 in text).

The following is a summary of the calculations this software makes. As a comparison between the ABMA curve of estimated carbon loss and the actual ash sample carbon analyses, a carbon balance was estimated. Using the steam integrator and calculated boiler efficiency, coal usage is estimated. Multiplying the coal tonnage by the percentage ash from the coal analysis gave the ash per hour fed to the boiler. To perform the carbon balance, the split between bottom and fly ash must be known. This split is estimated based upon the percentage of fines in the coal feed; the split is shown in Figure A1. The relationship shown is based upon Detroit Stoker's experience and, while its presupposition is founded on experience with hundreds of spreader stokers, it represents an average and the actual bottom ash/fly ash split may deviate significantly. Using the estimated split from Figure A1 and the calculated ash rate, the pounds of ash going to bottom ash and fly ash are calculated, assuming no accumulation in the boiler. Using the actual carbon analyses for the bottom ash, the pounds of carbon per hour entering the boiler can be calculated, while a further split in the fly ash must be assumed between mechanical collector fly ash and ESP fly ash. Removal efficiencies of 80 percent and 60 percent were used for the mechanical collector and ESP, respectively; the pounds of carbon per hour in the mechanical collector fly ash and ESP fly ash were calculated. The thermal efficiency loss due to unburned carbon is calculated from Equation A1.

$$\text{Thermal efficiency loss} = \frac{\text{total carbon (lbs/hr)} \times 14{,}087 \text{ Btu/lb}}{\text{coal feed rate (lb/hr)} \times \text{coal's HHV (Btu/lb)}} \qquad \text{[Eq A1]}$$

[4]*Power Test Code: Steam Generating Units.*

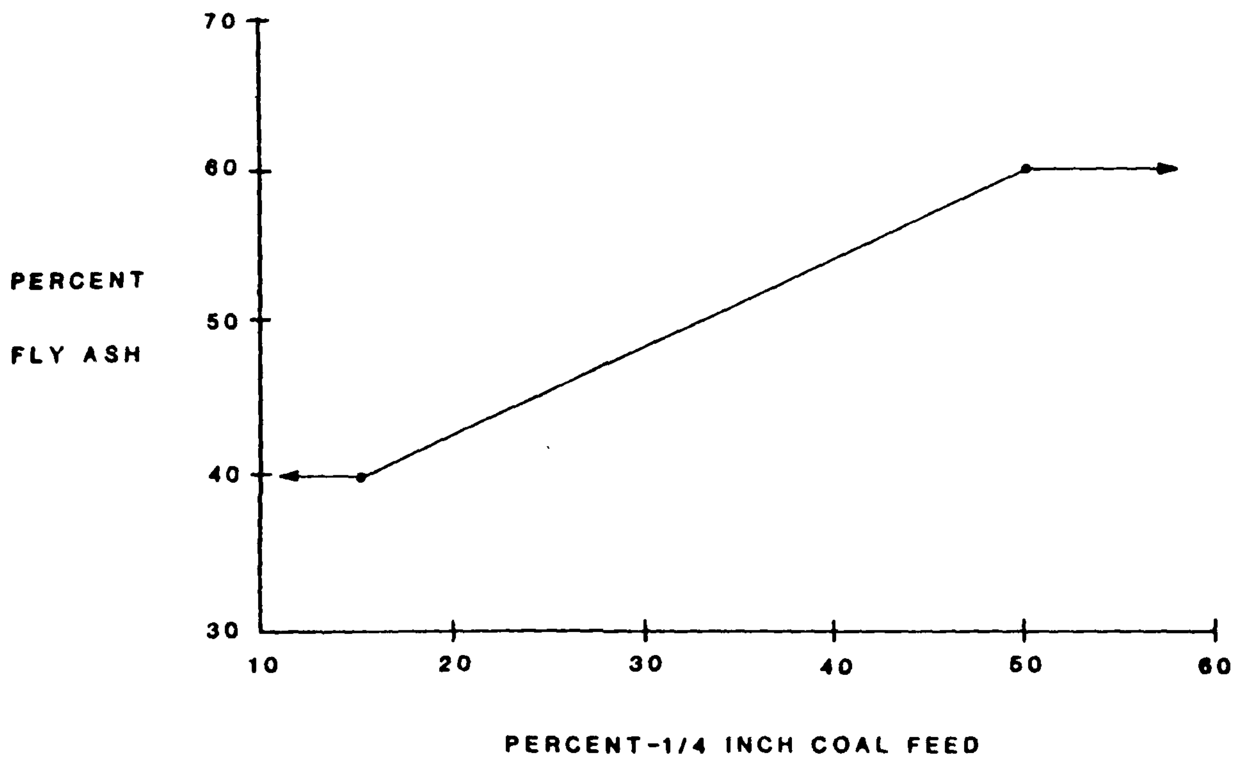

Figure A1. Percent fly ash vs. percent minus 1/4 in. coal feed.

SCHMIDT ASSOC'S. HOLSTON ARMY AMMUNITION PLANT SHT 1 OF 1
CONSULT'G ENGINEERS BOILER No. 1 JOB NO. 86-120-4
CLEVELAND OHIO CALCULATIONS TEST RUN No. 4/5 ON 22 JULY 1987

ALLOWABLE EMISSIONS PER LOCAL E.P.A. : 0.10 #/MMBTU PARTICULATE
??????? #/MMBTU SULPHUR

TABULATION OF EMISSION RESULTS - PARTICULATE/SULFUR

		P A R T I C U L A T E		
BASED ON	IN UNITS	RUN No.4	RUN No.5	AVERAGE
STACK	#/HR.	29.34	32.70	31.020
COAL 'F' FACTOR	#/MMBTU	0.2459	0.2711	0.2585
COAL SCALE	#/MMBTU	ERR	ERR	ERR
% BOILER LOAD	%	0.00%	0.00%	0.00%
INTEGRATOR	#/MMBTU	0.2863	0.3114	0.2988
% BOILER LOAD	%	48.75%	50.00%	49.38%
INDICATOR	#/MMBTU	0.2798	0.3038	0.2918
% BOILER LOAD	%	49.88%	51.25%	50.56%
ASME PTC 4.1 HEAT LOSS	#/MMBTU	0.2841	0.3084	0.2963
% BOILER LOAD	%	49.88%	51.25%	50.56%
ASME PTC 4.1 INPUT OUTPUT	#/MMBTU	ERR	ERR	ERR
% BOILER LOAD	%	49.88%	51.25%	50.56%

DURING RUN - BLEW SOOT	?	?
DURING RUN-PULLED BOTTOM ASH	?	?
DURING RUN - PULLED FLY ASH	?	?

		S U L F U R		
BASED ON	IN UNITS	RUN No.4	RUN No.5	AVERAGE
% IN FUEL	%	0.68%	0.69%	0.69%
SO2 (CALCULATED)	#/MMBTU	0.932	0.948	0.940

IDT ASSOCIATES
JLT'G ENGINEERS
ELAND OHIO

HOLSTON ARMY AMMUNITION PLANT
BOILER EFFICIENCY TEST DATA UNIT NO. 1 (COAL FIRED) TEST RUN No. 4
BABCOCK & WILCOX W/MDC., ECON., DETROIT SPREADER STOKER(294 SQ FT), & ESP   160 000 #/HR UNIT

SH'T 1 OF 6
JOB NO. E6-120-4
TESTED 22 JULY 1987

DATA PER FIELD INSTRUMENTATION (UNLESS NOTED)

TIME OF DAY MILITARY	STEAM DATA FROM BOARD: FLOW READING INTEGR'R 2000	STEAM DATA FROM BOARD: FLOW READING INDICA'R #/HR.	STEAM DATA FROM BOARD: TEMP. F	STEAM DATA FROM BOARD: DRUM PRES. PSIG	BOILER F.W. INTEGR'R 2000	WET FLUE GAS TEMPERATURES: ECON. OUT	WET FLUE GAS TEMPERATURES: ID FAN OUT	WET FLUE GAS TEMPERATURES: BLR. OUT	RELATIVE AIR FLOW	OXYGEN READINGS: BL'R. OUT	OXYGEN READINGS: ECON. OUT	OXYGEN READINGS: ID FAN OUT	TEMPERATURE: FW INTO ECON.	TEMPERATURE: BLR. F.W. PRESS.	DRAFT - INCHES WATER: DATA FROM BOARD: FD PRESS.	DRAFT - INCHES WATER: DATA FROM BOARD: UPTAKE DRAFT	DRAFT - INCHES WATER: DATA FROM BOARD: FURNACE	DRAFT - INCHES WATER: DATA FROM FIELD: BLR OUT	DRAFT - INCHES WATER: DATA FROM FIELD: ECON OUT	DRAFT - INCHES WATER: DATA FROM FIELD: ID FAN OUT	REMARKS
14:30	3379	80,000	508	300	4310	405	399	527	59	9.2%	11.6%	9.3%	230	370	0.3	1.0	0.08	0.8	1.7	0.2	
14:45		80,000	510	300		404	399	528	58	9.5%	10.6%	9.5%	230	370	0.3	1.0	0.08	0.8	1.6	0.3	
15:00		79,000	510	300		405	398	528	58	9.3%	10.2%	9.4%	230	370	0.3	1.0	0.08	0.9	1.6	0.2	
15:15		78,000	510	300		405	398	529	58	9.7%	10.3%	9.1%	230	375	0.3	1.0	0.08	0.9	1.7	0.3	
15:30	3418	82,000	510	300	4349	406	399	530	58	9.2%	11.1%	8.9%	230	375	0.3	1.0	0.08	1.0	1.6	0.2	
SUMMATION	39	79,800	510	300	39	405	399	528	58.2	9.4%	10.8%	9.2%	230	372	0.3	1.0	0.08	0.9	1.6	0.2	

SCALE INTEGRATOR MULTIPLIER = 1
COAL HEATING VALUE (BTU/#) = 13861

DIVIDED BY TEST DURATION = 1 HRS.
COAL SCALE TEST DURATION =1.075 HRS.

SAMPLE CALCULATIONS

1-STEAM PRESSURE = 300
2-ATMOS PRESSURE = 15

ABSOL PRESS PSIA = 315 SATURATED @ 509.6 DEG. F. = 1262 BTU/# ENTHALPHY
3-FEEDWATER @ 230 DEG. F. = 198 BTU/# ENTHALPHY

DIFFERENCE = 1064 BTU/# OF STEAM

4-DESIGN PARAMETERS FROM TEST DATA FOR CALCULATIONS:
A)SCALE INTEG. = 0 x MULTIPLIER OF 1 = # & / TIME = 0 Lbs/Hr. COAL
B) FLUE GAS EXIT TEMP. DEG. F. = 405 OR DENSITY =0.0478 #/CU. FT.
C) HEAT OUTPUT @ MCR = 170,217,600 BTU/Hr.

5-CALCULATION OF EFFICIENCY: COMBUSTION PER FUEL CURVE = 83.57%FROM SHT 5 OF 6
CARBON LOSSES = 1.80%
RADIATION LOSSES = 0.80%

% THERMAL EFF.= 80.97 NET FOR CALC'S.

6-INPUT @ COALS HHV OF 13,861 BTU/# 0 BTU/Hr. HEAT INPUT
A) OUTPUT = INPUT * THERMAL EFFICENCY = 0 BTU/Hr. HEAT OUTPUT
B) CALCULATED QUANTITY OF STEAM FLOW IS = 0 #/Hr. STEAM
C)INTEG. WITH A2000 MULTIPLIER = FLOW OF 78,000 #/Hr. STEAM
D) INDICATOR AVERAGED FLOW DURING TEST = 79,800 #/Hr. STEAM

7) FLOW @ XCA % = 20 @ WG/# COAL / CURVE = 0 #/HR
OR 0 ACFM @ 405 DEG. F

COMPARISION OF CALCULATED VALUES

SOURCE OF DATA USED AS BASES FOR CALCUATIONS	STEAM FLOW LBS/HR	WET (FLUE) GAS FLOW LBS/HR	FUEL (COAL) USED SCALE LBS/HR
COAL USAGE	0	0	0
INTEGRATOR	78,000	144,537	7,394
INDICATOR	79,800	147,873	7,565
ASME HEAT LOSS	79,800	145,621	7,449
ASME INPUT OUTPUT	79,800	ERR	ERR

DEVIATIONS OF CALCULATED VALUES (%)

SOURCE OF MEAN DEVIATION FROM BASE (COAL SCALE)	STEAM FLOW LBS/HR	WET (FLUE) GAS FLOW LBS/HR	FUEL (COAL) USED SCALE LBS/HR
INTEGRATOR	ERR	ERR	ERR
INDICATOR	ERR	ERR	ERR
ASME HEAT LOSS	ERR	ERR	ERR
ASME INPUT OUTPUT	ERR	ERR	ERR

USING RESULTS FROM ASME PTC 4.1

USING ASME PTC 4.1 EFFICIENCIES TO CALCULATE HEAT INPUTS

1) DESIGN PARAMETERS FROM TEST DATA:
A) STEAM LOAD = 79,800 #/HR.
B) AIR HTR. OUT GAS (AVG.) TEMP. F = 405
C) EXCESS AIR = 77. % @ TEST POINT & FLUE GAS DENSITY =0.048 #/CU. FT.

2) ASME PTC 4.1 HEAT LOSS METHOD THERMAL EFFICIENCY = 82.22%FROM SHT 5 OF 6

A) OUTPUT @ 1064 BTU/#	79,800 #/HR.=	84,896,028	BTU/HR
1) INPUT = OUTPUT / THERMAL EFFICIENCY =		103,255,824	BTU/HR
2) CALCULATED QUANTITY OF COAL USED IS =		7,449	#/HR
3) TEST DATA QUANTITY OF COAL USED IS =		0	#/HR
4) % DIFFERENCE QUANTITY OF COAL IS =		100.00	%
B) FLOW @ XCA % = 20 # WG/# (FUEL CURVE) =		145,621	#/HR
OR	50,783 ACFM @	405	DEG. F

3) ASME PTC 4.1 INPUT OUTPUT METHOD THERMAL EFFICIENCY = ERR FROM SHT 5 OF 6

A) OUTPUT @ 1064 BTU/#	79,800 #/HR.	84,896,028	BTU/HR
1) INPUT = OUTPUT / THERMAL EFFICIENCY =		ERR	BTU/HR
2) CALCULATED QUANTITY OF COAL USED IS =		ERR	#/HR
3) TEST DATA QUANTITY OF COAL USED IS =		0	#/HR
4) % DIFFERENCE QUANTITY OF COAL IS =		ERR	%
B) FLOW @ XCA % = 20 # WG/# (FUEL CURVE) =		ERR	#/HR
OR	ERR ACFM @	405	DEG. F

SCHMIDT ASSOCIATES — ABBREVIATED A.S.M.E. EFFICIENCY TEST FORM — SHEET 5 OF

CONSULTING ENGINEERS — TEST RUN No. 4 — JOB NO. 86-120-4

CLEVELAND OHIO — OBJECTIVE - COMPLIANCE — TESTED : 22 JULY 19_

OWNER OF PLANT: UNITED STATES ARMY — LOCATION: KINGSPORT, TENN.

UNIT No. MAKE & TYPE: BABCOCK & WILCOX STEAM BOILER No. 1 — RATED CAPACITY: 160,000 #/Hr.

STOKER, TYPE & SIZE: DETROIT SPREADER STOKER W/TRAVELING GRATE (294 SQ FT)

PULVERIZER, TYPE & SIZE: ------------Not Applicable----------- BURNER, TYPE & SIZE:----------------- Not Applicable ---------

FUEL,TYPE & SIZE(AS FIRED): BITUMENOUS STOKER COAL (1 1/4 x 0) MINE,COUNTY & STATE:____________________

PRESSURES & TEMPERATURES			FUEL DATA			
1 STEAM PRESSURE IN BOILER DRUM	psia	315	COAL AS FIRED PROX. ANALYSIS : % wt.		OIL	
2 STEAM PRESSURE AT S. H. OUTLET	psia		37 MOISTURE	2.07	51 FLASH POINT F *	
3 STEAM PRESSURE AT R. H. INLET	psia		38 VOL. MATTER	31.7	52 SP. GRAVITY DEG. API *	
4 STEAM PRESSURE AT R. H. OUTLET	psia		39 FIXED CARBON	59.28	53 VISCOSITY AT BURNER SSU*	
			40 ASH	6.95	SSF*	
5 STEAM TEMPERATURE AT S. H. OUTLET	F		TOTAL	100	44 TOTAL HYDROGEN % wt.	
6 STEAM TEMPERATURE AT R. H. INLET	F		41 BTU per lb AS FIRED	13,861	41 BTU per lb AS FIRED	
7 STEAM TEMPERATURE AT R. H. OUTLET	F		42 ASH SOFT TEMP ASTM METHOD:			
8 WATER TEMP. ENTERING BOILER	F	230			GAS	% VOL
9 STEAM QUALITY % MOISTURE OR P.P.M.			COAL OR OIL AS FIRED ULTIMATE ANAL.		54 CO	
10 AIR TEMP. AROUND BOILER (AMBIENT)	F	80	43 CARBON	77.63	55 CH4 METHANE	
11 TEMP. AIR FOR COMBUSTION (THIS IS REF. TEMP)*	F	80	44 HYDROGEN	4.81	56 C2H2 ACETYLENE	
12 TEMPERATURE OF FUEL	F		45 OXYGEN	6.50	57 C2H4 ETHYLENE	
13 GAS TEMP.LEAVING Air Htr.	F	405	46 NITROGEN	1.36	58 C2H6 ETHANE	
14 GAS TEMP. INTO AH (If conditions to be corr'd. to guar.)			47 SULPHUR	0.68	59 H2S	
UNIT QUANTITES			40 ASH	6.95	60 CO2	
15 ENTHALPY OF SAT. LIQUID (TOTAL HEAT)	Btu/lb	399	37 MOISTURE	2.07	61 H2 HYDROGEN	
ENTHALPY OF SATURATED STEAM	Btu/lb	1262.0	TOTAL	100	TOTAL	0
17 ENTHALPY OF SATURATED FEED TO ECONOMIZER.	Btu/lb	198.23	COAL PULVERIZATION		TOTAL HYDROGEN % wt	
18 ENTHALPY OF REHEATED STEAM R. H. INLET	Btu/lb		48 GRINDABILITY INDEX *		62 DENSITY 68 F ATM. PRESS.	
19 ENTHALPY OF REHEATED STEAM R. H. OUTLET	Btu/lb		49 FINENESS % THRU 50 M *		63 Btu PER CU FT	
20 HEAT ABS/LB OF STEAM (ITEM 16-ITEM 17)	Btu/lb	1063.8	50 FINENESS % THRU 200 M *			
21 HEAT ABS/LB R. H. STEAM (ITEM 19-ITEM 18)	Btu/lb	0	64 INPUT - OUTPUT EFFICENCY OF UNIT % (ITEM 31 x 100)/ITEM 29			ERR
22 DRY REFUSE (ASH PIT+FLY ASH) PER LB AS FIRED	lb/lb		HEAT LOSS EFFICIENCY		Btu/lb AF FUEL	% AF FUEL
23 Btu PER LB IN REFUSE(WEIGHTED AVERAGE)	Btu/lb		65 HEAT LOSS DUE TO DRY GAS		1488.470758	10.74%
24 CARBON BURNED PER LB AS FIRED FUEL	lb/lb	0.7763	66 HEAT LOSS DUE TO MOISTURE IN FUEL		18.611577	0.13%
25 DRY GAS PER LB AS FIRED FUEL BURNED	lb/lb	19.082	67 HEAT LOSS DUE TO H2O FROM COMB OF H2		389.224719	2.81%
HOURLY QUANTITIES			68 HT.LOSS-COMBUST.IN REFUSE/CARB. LOSS		0	1.80%
26 ACTUAL WATER EVAPORATED	lb/hr	79800	69 HEAT LOSS DUE TO RADIATION		0	0.50%
27 REHEAT STEAM FLOW	lb/hr		70 UNMEASURED LOSSES **			1.50%
28 RATE OF FUEL FIRING (AS FIRED wt)	lb/hr	0	71		TOTAL	17.78%
29 TOTAL HEAT INPUT (ITEM 28 x ITEM 41)/1000	kB/hr	0	72 EFFICIENCY = (100 - ITEM 71)			82.22%
30 HEAT OUTPUT IN BLOW-DOWN WATER	kB/hr	0.2007				
31 TOTAL ((ITEM26xITEM20)+ITEM27xITEM21)+ITEM30			66A INSERT ENTHALPY OF VAPOR AT 1 psia & @ TEMP (ITEM 13)			1244.02
HEAT ---------------------------------------	kB/hr	84,896	66B INSERT ENTHALPY OF LIQUID AT TEMP (ITEM 11)			344.91
OUTPUT 1000			69A INSERT TOTAL BTU RADIATION LOSS PER HOUR			????????
FUEL GAS ANALYSIS (BOILER) OR (ECON.) OR (AIR HTR.) OUTLET			69B INSERT QUANTITY IN POUNDS OF AS FIRED FUEL			0
32 CO2	% VOL	10.206	70A INSERT UNMEASURED LOSSES IF KNOWN OR USE THE A.B.M.A.			0.015
33 O2	% VOL	9.3832	STANDARD RADIATION LOSS CHART,FIG. 8, PTC 4.1-1964			0.008
34 CO	% VOL	0	CARBON LOSS FROM A.B.M.A. CURVES			0.018
35 N2 (BY DIFFERENCE)	% VOL	80.410				
36 EXCESS AIR **	%	77.020	* FOR POINT OF MEASUREMENT SEE PAR 7.2.8.1-PTC 4.1-1964			
			* NOT REQUIRED FOR EFFICENCY TESTING			

FOR RIGOROUS DETERMINATION OF EXCESS AIR SEE APPENDIX 9.2 -PTC 4.1-1964

** UNMEASURED LOSSES LISTED IN PTC 4.1 BUT NOT TABULATED ABOVE MAY BE PROVIDED FOR BY ASSIGING A MUTUALLY AGREED UPON VALUE FOR ITEM 70

COMBUSTION EFFICIENCY

PROXIMATE ANALYSIS OF FUEL		ULTIMATE ANALYSIS OF FUEL	
VOLATILE MATTER =	31.70%	CARBON =	77.63
FIXED CARBON =	59.28%	HYDROGEN =	4.81
ASH =	6.95%	SULPHUR =	0.68
MOISTURE =	2.07%	OXYGEN =	6.50
TOTAL =	100.00%	NITROGEN =	1.36
		CHLORINE =	0.00
HEATING VALUE =	13,861 BTU/Lb.	ASH =	6.95
		MOISTURE =	2.07
		TOTAL =	100.00 %

TEST CONDITIONS OF: 80.0 DEGREES COMBUSTION AIR
405.0 DEGREES FLUE GAS TEMPERATURE
9.38 OXYGEN IN FLUE GAS (PROBE)

PRODUCE THE FOLLOWING CALCULATED RESULTS :

NET GAS/# Fuel = 19.548 OR = 6.82 ACFM @ FLUE GAS TEMP. OF 405 DEG. F
COMB AIR/# Fuel = 18.618 OR = 4.22 ACFM @ COMBUSTION AIR TEMP. 80 DEG. F
DRY GAS/# Fuel = 19.098

CARBON DIOXIDE = 10.206% EXCESS AIR = 79.90% SEE NOTE
OXYGEN = 9.383% EFFICIENCY = 83.567%

NOTE: TRIAL OF EXCESS AIR VALUES UNTIL CALCULATED O2 = TESTED O2.

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